HYPERSONIC ARBITRARY-BODY AERODYNAMIC COMPUTER PROGRAM (MARK III VERSION)

VOLUME I USER'S MANUAL

BY
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APRIL 1968

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267

MCDONNELL DOUGLAS CORPORATION

HYPERSONIC ARBITRARY-BODY AERODYNAMIC COMPUTER PROGRAM

MARK III VERSION

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FOREWORD

This report describes a computer program developed at the Douglas Aircraft Division of the McDonnell Douglas Corporation, Long Beach, California. The development of the Douglas Hypersonic Arbitrary-Body Aerodynamic Computer Program was started in 1964 and greatly expanded in subsequent years under sponsorship of the Douglas Independent Research and Development Program (IRAD). From August 1966 to May 1967 the program development was continued under Air Force Contract No. F3361567 C 1008. This contract was administered under the direction of the Aeronautical Systems Division, Directorate of Analysis, Wright-Patterson Air Force Base, Ohio, by Mr. R. K. Mills, Project Engineer (ASBED-30). The product of this work was the Mark II version of the program as released for use by government agencies in May 1967. The latest version of the program as presented in this report (the Mark III version) is an extensively revised version of the earlier Mark II program. This version has been prepared as a result of both 1967-68 Douglas IRAD work and another Air Force contract (F33615 67 C 1602). This contract was administered by the Air Force Flight Dynamics Laboratory, Flight Mechanics Division, Gas Dynamics Branch, Mr. Valentine Dahlem, Project Engineer (FDMG).

At the Douglas Aircraft Division, this work was conducted under the direction of Mr. A. E. Gentry as Principal Investigator. A number of people contributed to the various phases of this work for which the author is grateful. Mr. D. N. Smyth provided valuable consulting services in many phases of this work and prepared the new skin friction techniques incorporated in the Mark III version. Mr. W. R. Oliver's work in applying the various versions of this program to practical design problems contributed both in program design and in program validation. Others participating in this work include Messrs. G. D. Buell, J. L. Lundry, N. F. Wasson, and B. G. Wilson.

Special appreciation is extended to the various users of the earlier versions of this program for their valuable suggestions in a number of areas and for their efforts in adapting and running earlier versions of the program on the different types of computers. These include Messrs. Fred White, Jr. (Air Force ASBED-30), Don Shereda (Air Force FDMG), Ralph Carmichael and Charles Castolano (NASA Ames), C. L. W. Edwards (NASA Langley), Ralph Grahm (NASA Houston), Ray E. Aley (Lockheed Electronics Co., Houston), and R. E. Finch, A. W. Marziane, and J. H. Kainer (Aerospace Corp.).

This computer program and documentation report was released for general use by the author and by the Guidance and Control Section, ASBED-30, Wright-Patterson Air Force Base, in April 1968. This program and report are provided in the interest of information exchange. Responsibility for the contents rests with the author or organization that prepared it.

The distribution of computer program decks for the Mark III version is handled by the author.

ABSTRACT

This report describes a digital computer program system that is capable of calculating the hypersonic aerodynamic characteristics of complex three-dimensional shapes. The outstanding features of this program are its flexibility in covering a very wide variety of problems and the multitude of program options available. The program is a combination of techniques and capabilities necessary in performing a complete aerodynamic analysis of hypersonic shapes. These include vehicle geometry generation and description, visual graphics necessary in handling geometry data and in preparing plots of the final aerodynamic data, aerodynamic calculations of surface pressures and skin friction forces, and the integration of these forces to give all aerodynamic coefficients and stability derivatives.

The geometric description techniques in this program provide the capability of handling completely arbitrary three-dimensional shapes. The procedure developed to check the accuracy of the geometric data uses a computer and automatic recorder to draw pictures of the vehicle viewed from any angle.

The pressure calculation methods provided within the program include modified Newtonian, blunt-body Newtonian-Prandtl-Meyer, tangent-wedge, tangent-cone, shock-expansion, Prandtl-Meyer expansion, blast wave, modified tangent-cone, boundary-layer induced pressures, free-molecular flow, and a number of empirical relationships. The pressure calculation method most suitable for each component of the vehicle is specified by the aerodynamicist. Viscous forces are also calculated and include viscous-inviscid interaction effects. Skin friction options include the Reference Temperature and the Reference Enthalpy methods (for both laminar and turbulent flow), the Spalding-Chi method (turbulent), and a special blunt body skin friction method. Control surface deflection pressures, including separation effects that may be caused by the deflected surface, are also calculated.

The program has been used to study a wide variety of hypersonic vehicle shapes including hypersonic cruise aircraft, air-breathing booster aircraft, blunt lifting reentry bodies, high L/D reentry vehicles, blunt reentry capsules, rocket boosters, reentry warheads, and satellite shapes.

The program is documented in two volumes. Volume I is primarily a User's Manual, and Volume II contains the Program Formulation and Listings.

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

ILLUSTRATIONS

SECTION 1

INTRODUCTION

The program described in this manual is identified as the Mark III version of the Douglas Hypersonic Arbitrary-Body Aerodynamic Computer Program. This computer program consists of several major program components controlled by an executive main program. The program components are designed to provide the user with a complete geometric description of a vehicle shape in a form useful to the computer, picture-drawing techniques to permit the rapid checking and verification of the geometry, force-analysis techniques for calculating the aerodynamic characteristics, and finally, graphical automatic plotting of the characteristics. Together, these components provide the necessary capabilities for performing all of the tasks required in the preliminary-design aerodynamic analyses of hypersonic shapes. The program is written in FORTRAN for use on such computers as the IBM 360/65, IBM 7094, and the UNIVAC 1108. The program contains graphics capabilities requiring use of the SC-4020 Automatic Recorder.

The solution of a problem starts with the preparation of the geometry data. The vehicle shape data are prepared completely independent of the pressure calculations. This provides complete flexibility in geometry description, yet provides for a proper re-combination of the geometry data and the pressure computation method for calculation of the aerodynamic characteristics. A shape is normally described on a component build-up basis to facilitate the use of different geometry generation techniques on different parts of the vehicle, and to permit use of different pressure calculation methods on each component. Each component can be completely arbitrary in shape.

All geometry data finally used by the program are in a single form using a large number of plane quadrilateral surface elements distributed over the surface of the vehicle. However, these data may originate in a number of different forms. These include input surface elements, larger patch surfaces described by the parametric cubic method, or elliptical or circular arc vehicle sections. In addition, for those surfaces that are analytical, auxiliary geometry generation routines may be used. For parametric studies of particular families of shapes, the geometry may be generated by separate routines or programs prepared for this purpose. The capability is also provided to mix these various geometry input schemes in any manner desired.

Once the surface geometry is described for the computer, the vehicle forces may be calculated. The aerodynamic literature contains descriptions of many different methods of calculating the pressures on hypersonic vehicles. Each method is tailored to a particular application, either by the geometry assumed or by the assumptions made in the gas-dynamics relationships. It is obvious that no one method will suffice for all shapes and flight conditions. Indeed, different methods must frequently be used for different components of a single vehicle. The logical conclusion is that the analysis system must include a number of different force-calculation methods to use for different vehicle component shapes and flight conditions. As new methods are devised and validated, they may be added to the analysis system.

The selection of a particular method or methods for a given vehicle depends on the vehicle component shape and the flight condition involved. The present program (Mark III Mod 0 version) contains the following pressure calculation options: (1) modified Newtonian, (2) blunt-body Newtonian-Prandtl-Meyer, (3) tangent-wedge, (4) tangent-wedge empirical, (5) tangent-cone, (6) OSU Blunt-Body empirical, (7) Van Dyke unified, (8) high Mach base pressure, (9) shock-expansion, (10) free-molecular flow, (11) input pressure, (12) Hankey flat-surface empirical, (13) Prandtl-Meyer expansion, (14) Dahlem-Buck empirical, (15) blast wave, (16) modified tangent-cone, and (17) boundary-layer induced pressure. The method to be used in impact and shadow regions may be specified independently.

The program also calculates skin friction forces. Because of the more complex nature of these calculations a less detailed set of geometry data are used. The local flow properties on each of the surfaces are calculated and then the resulting radiation equilibrium wall temperature and skin friction forces are determined using the selected viscous method. The methods provided are the Reference Temperature and Reference Enthalpy methods (for both laminar and turbulent), and the Spalding-Chi method (turbulent). In addition a specialized shear-force method is provided for use on blunt bodies. The effects of viscous-inviscid interaction on the skin friction are also calculated. Also, a pressure method option is included in the program to calculate induced pressure forces due to these interaction effects. These calculations are made on the skin friction geometry model rather than the pressure geometry model.

The program also has the capability of calculating control surface deflection effects on the vehicle characteristics. These calculations include, not only the changes in control surface pressures, but the changes in pressure on other parts of vehicle that may be influenced by boundary layer separation effects caused by the deflected control surface. Any number of control surfaces may be used and they may all be deflected in different directions if desired.

In addition to the aerodynamic capabilities discussed above, the program also contains several other specialized options. Using conventional methods the program may be used to calculate the dynamic damping derivatives $C_{m_{\dot{\alpha}}}$ and $C_{Y_{\dot{\beta}}}$ for wing-body-tail configurations. Also, since some vehicles may be strongly influenced by other applied force-vector effects (such as those caused by air-breathing propulsion systems), capabilities are also provided for including these factors along with the conventionally calculated aerodynamic forces.

The output data obtained from this program may be varied, depending upon the problem requirements. These data may range from just the final vehicle force coefficients to detailed surface pressure distributions. Input flags are provided for obtaining the results of intermediate program calculations. The program output contains the following parameters as functions of angle of attack and sideslip angle: C_D, C_L, C_A, C_Y, C_N, L/D, C_m, C_ℓ, C_n, C_{A_α}, C_{L_α}, C_{N_α}, C_{m_α}, C_{m_q}, C_{A_q}, C_{N_q}, C_{Y_β}, C_{n_β}, C_{ℓ_β}, C_{Y_r}, C_{n_r}, C_{ℓ_r}, C_{m_δ}, C_{ℓ_δ}; C_{Y_δ}, C_{n_δ}, C_{N_δ}, $C_{m_{\dot{\alpha}}}$, $C_{Y_{\dot{\beta}}}$, and hinge moments.

From the proceeding discussions we may conclude that the Hypersonic Arbitrary-Body Aerodynamic Computer Program may be useful in a wide variety of hypersonic vehicle design studies. This is graphically illustrated by the presentation in Figure 1 of the selection of drawings of some of the hypersonic shapes that have been studied with this program.

Users of the previous versions of this program may well inquire as to the differences between the present Mark III program and the earlier Mark II version. First of all, the major features of the program as described in the Mark II program report (Reference 1) have remained unchanged. All old problem decks will still run on the new program, although in some cases the answers produced will be slightly different. The Mark III version of the program contains a number of new program features and capabilities that will simplify the deck set-up for some problems, and that will provide improved accuracy in the aerodynamic calculations for many applications. A brief outline of some of these new capabilities is given below.

1. A new option has been added to permit the use of input surface elements in describing the geometry for the skin friction calculations. This permits the various skin friction surfaces to be oriented anywhere in space to represent the actual geometric shape. The skin friction contributions to the vehicle moment coefficients are now calculated under this option.

2. The skin friction subroutines have been extensively modified to provide the capability of calculating both Reference Temperature and Reference Enthalpy skin friction results. In addition to these methods the Spalding-Chi technique is provided as an alternate turbulent skin friction calculation option.

3. Induced pressures and skin friction results using the tangent-cone pressure method now include a correction for 3-D effects.

4. The skin friction calculations now use a linear relationship for viscosity at low temperatures rather than a power-law relationship. This will give more accurate skin friction results for low free-stream temperature wind tunnel conditions.

5. The skin friction pressure option called DELWING now calculates tangent-cone values instead.

6. An additional geometry flag option has been provided to simplify the geometry data preparation for highly swept surfaces. This avoids the possibility of zero area leading edge elements that would cause trouble in shock-expansion calculations.

7. The program will now handle all-movable tail surfaces.

8. The new program pressure calculation options are

   8 Blunt-body skin friction
   14 Dahlem-Buck empirical method
   15 Blast wave pressure increments
   16 Modified tangent-cone
   17 Boundary layer induced pressures

The computer program is written on a modular basis to facilitate checkout and revision work. The entire program is written in the FORTRAN language. The original Mark II program was checked out on the IBM 7094 computer with 32,000 words of storage. Even though the program has increased in size a revision of the overlay structure still permits the programs use on the IBM 7094. Models of the Mark III program are available for use on the IBM 360, the IBM 7094, and the UNIVAC 1108 computers. For the Mark III program the IBM 360 model is considered to be the base-line program. The differences between the programs are of a minor nature and modifications necessary for operation on other similar computers should be easy to accomplish.

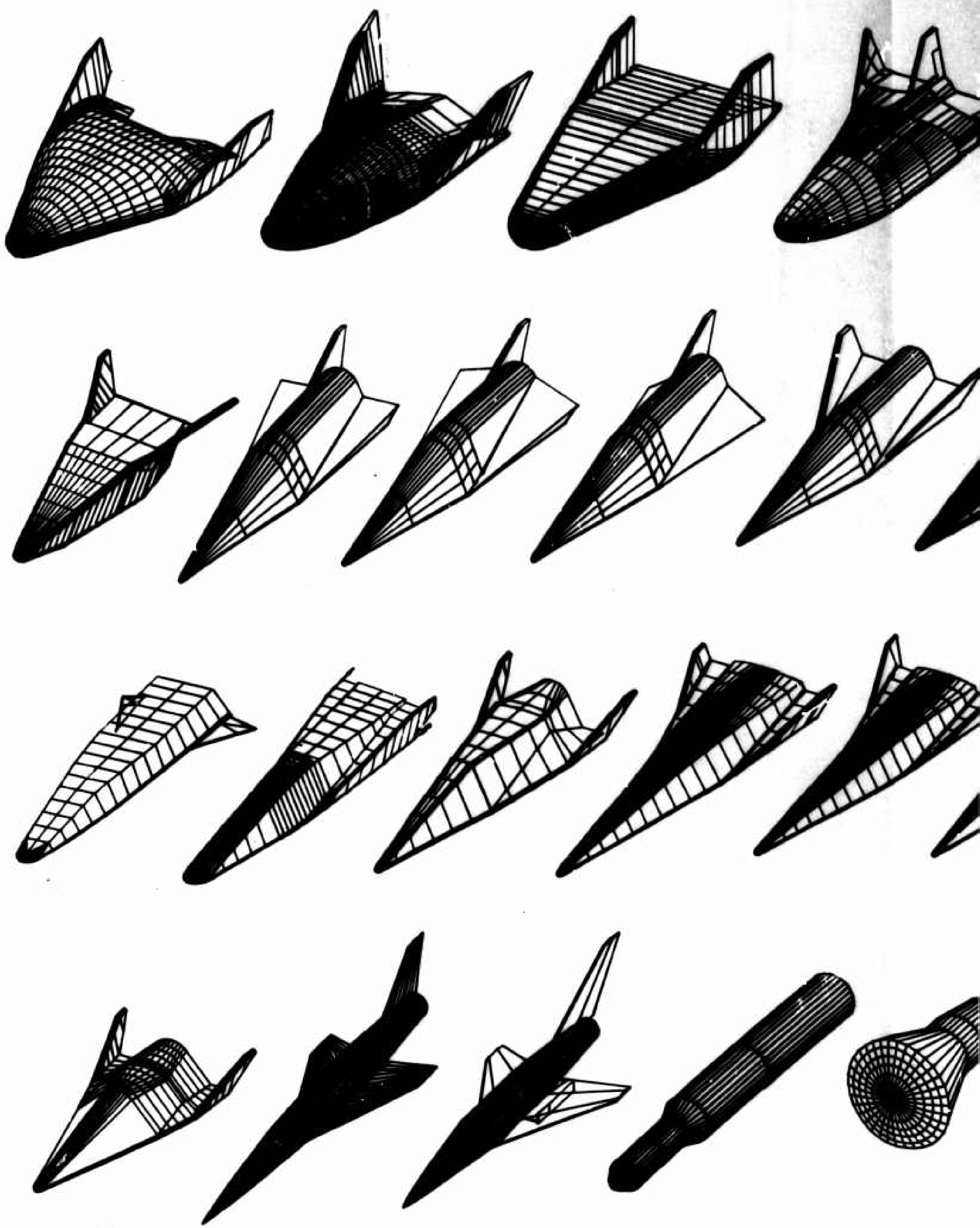
This computer program system uses a free-form approach to the preparation of the input data. That is, the order of the input cards depends upon the requirements of the problem being solved. This is true of both the system control data and of the input data to each of the major program components.

The program is entitled "Hypersonic Arbitrary-Body Aerodynamic Computer Program." This title brings with it certain inherent problems. If we are going to permit a completely arbitrary shape, we will have to use a large amount of data in describing it for the computer – we must be willing to pay something for the freedom of arbitrariness. Also, since no single pressure-calculation method will give good answers for all possible vehicle shapes under all hypersonic flight conditions, we must have available and know how to use a large number of force-calculation methods.

The basic approach in the design of this computer program system has been an attempt to minimize the difficulties caused by these two problem areas. The program has been designed so that simple problems are very easy to set up and run. However, the program is written with a great deal of flexibility, enough to handle almost all situations that may arise. With the more complex problems, the input also becomes a little more complicated.

The user of this program is cautioned to follow closely the instructions given in this manual. However, as with any similar document, no written manual is a substitute for a complete understanding of the problem to be solved, a methodical approach to the preparation and checking of the input data, and a careful analysis of the output data. Also, the accuracy of this program in any given application depends upon the wisdom of the engineer in selecting the proper force-calculation methods.

The reader should review the Table of Contents to get some idea as to how this report is organized. The first few sections discuss the more general aspects of problem solving with this computer program, followed by a detailed description, card by card and column by column, of all the input data. A liberal use is made of flow charts and diagrams to aid the user in understanding the input data requirements and the use of the program in solving any given problem. In the preparation of any part of the input data, such as the geometry data, the user needs a basic understanding of the operation of all other features of the program. He should, therefore, read the entire manual before attacking any part of a new problem.



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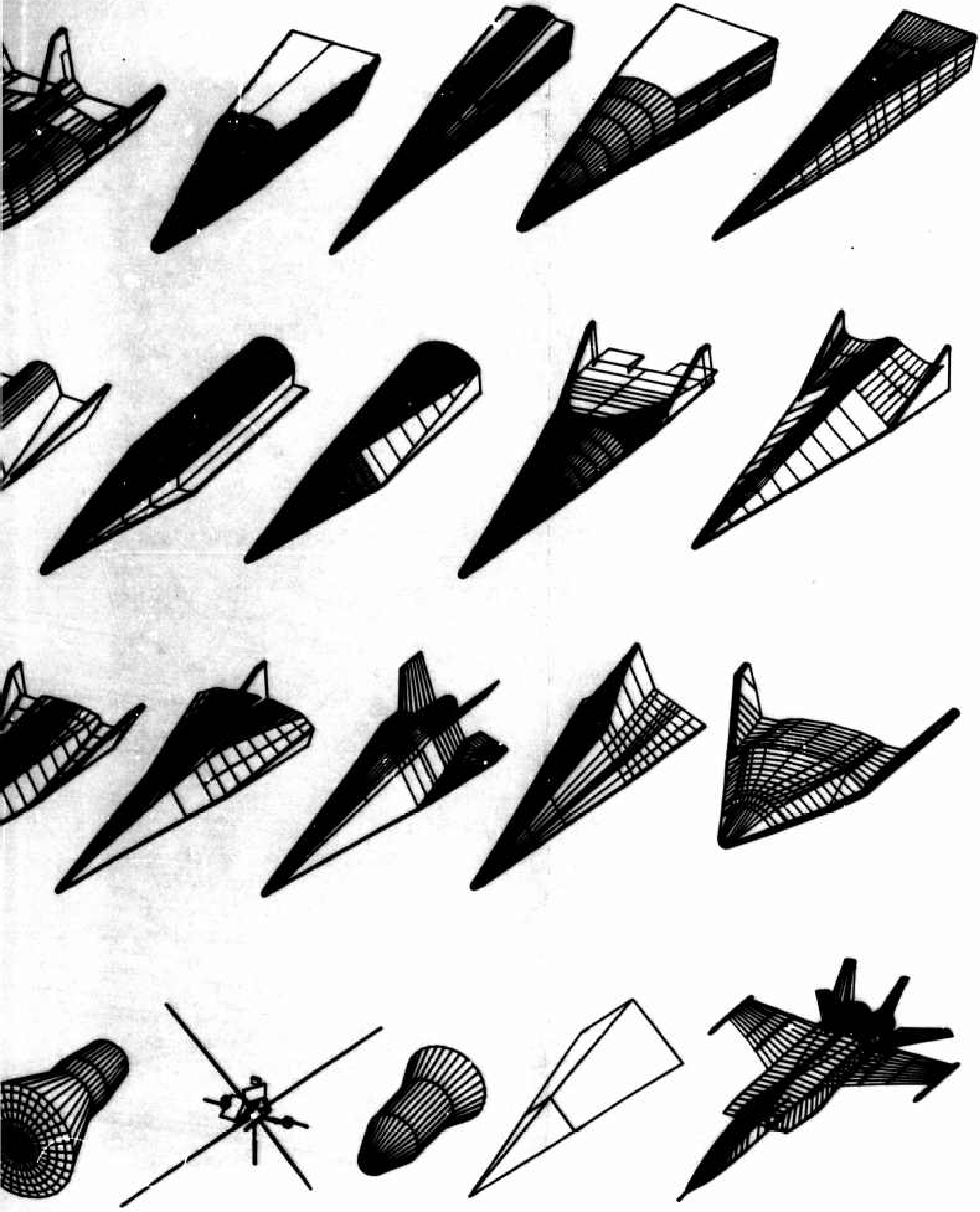

Figure 1. A Selection of Configurations That Have Been Studied With The Hypersonic Arbitrary-Body Program.

B

Appendix A contains a discussion of the approach to be used in selecting and using the force calculation methods. Appendix B contains a detailed sample problem that illustrates most of the features of the program. This sample should be studied, in order to gain a more thorough understanding of the use of the various features of the program.

Appendix C contains samples of all the program input sheets and a set of input data charts. These sheets are printed on fold-out pages to provide ready reference when studying the detailed data input instructions. The fold-out pages also contain greatly condensed outlines of the input data flags. The outlines will prove helpful once the user becomes thoroughly familiar with the problem-solving techniques provided by the program. Appendix D contains vellum originals of all the input sheets required to operate this program.

The theoretical considerations underlying the techniques used in the program are described in Volume II (Program Formulation and Listings).

Both Volumes I and II of this report are essentially revised editions of the earlier Mark II program report (Reference 1). The differences between the Mark III and Mark II reports reflect the modifications and new capabilities provided by the latest version.

A brief summary of the capabilities provided by the Arbitrary-Body Program is presented in Reference 2.

As with any program of this size, it is expected that modifications and corrections may be made from time to time. It will, therefore, be to the user's advantage to keep the author of this report informed of the name and address of the person responsible for maintenance of the program, so that changes can be supplied to him. Any errors noted in the program should be brought to the attention of the author. Suggestions for program improvement and extensions are invited.

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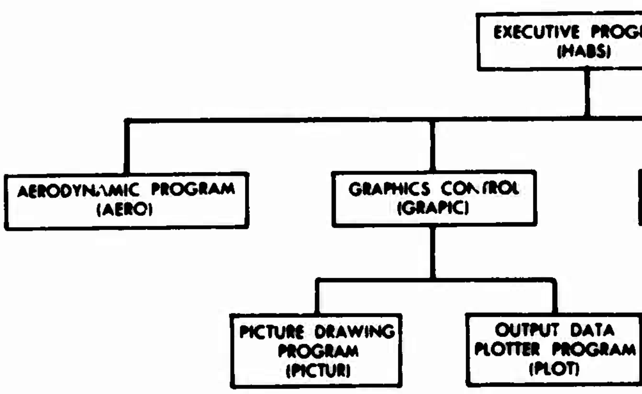
SECTION II

HYPERSONIC ARBITRARY BODY PROGRAM

GENERAL DESCRIPTION

The Hypersonic Arbitrary-Body System is composed of several major program components. The selection of the order of solution of the various components is controlled by a small executive program. The general arrangement of this system is shown in the diagram below.



Each of the major components is actually a separate computer program. They have been combined, by the use of the executive main program, to give one new and rather large program. However, the discussions throughout this manual will frequently use the term "program" in a rather loose sense when referring to any one of the major components.

The most important component of the system is the Aerodynamic (AERO) program. This part of the system is used for performing all aerodynamic calculations, for the generation of specialized geometry data required in these computations, and for storing both the vehicle geometry and final vehicle coefficients for use in the graphics part of the system.

The graphics part of the system has two components – the Picture-Drawing Program (PICTUR) and the Output Data Plotter Program (PLOT). These two components serve very important functions. Any method used to describe a complex shape for use in a computer program is plagued by the difficult problem of detecting errors in the input data. This problem is completely solved by the use of the Picture Drawing Program. This section of the system accepts the surface-geometry input data and uses the SC-4020 automatic data plotter to draw a picture of the resulting vehicle shape. The use and results of this computer program are best demonstrated by the examples presented in Figure 2. The viewing angle of these

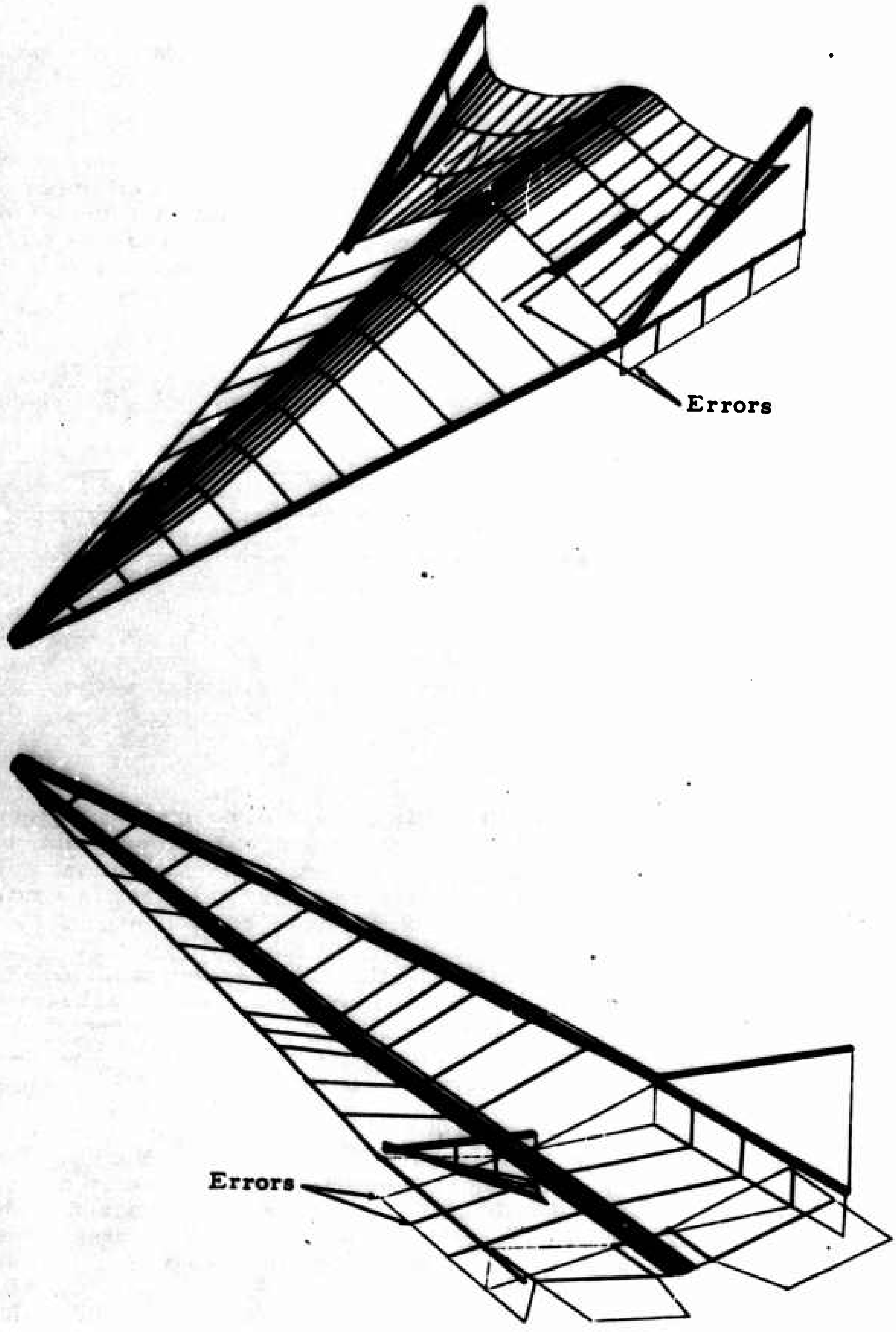


Figure 2. Error Detection with Picture Drawing Program

pictures is controlled by three input matrix rotation angles in a yaw-pitch-roll sequence. In general use, several pictures are made of the vehicle with different viewing angles in order to insure that all errors are detected. In addition, individual sections or rows of elements may be plotted with grid scales to detect small errors that may not appear in the more realistic drawings. A sample picture is shown in Figure 3. Once the input-data errors are identified, they may be corrected and the data resubmitted to the program for aerodynamic-force calculations.

The other component of the graphic phase of the program is the Output Data Plotter Program. The Aerodynamic Force Program calculates the vehicle characteristics and stores the results on a tape for use by the plotter program. The plotter program uses these data and prepares a tape for use by the SC-4020 automatic plotter. The output from this operation is illustrated in Figures 4 and 5. The possible saving in time required to prepare plotted aerodynamic data is obvious.

The next component of this system is the Slab Delta Geometry Generation Program (SLABD). In many design investigations it is desired to conduct studies of a large number of simple parametric shapes in order to gain an understanding of the effect of configuration variables on the vehicle aerodynamic characteristics. Such configurations can be easily derived by using analytical shape-generation techniques similar to those employed in the Slab Delta Geometry Generation option. The objective in these cases is to obtain the detailed geometric information required by the aerodynamic calculations with a minimum of input information. It is recognized that there will not be much need for the Slab Delta part of this system. The purpose in including it in this program is to show exactly how the systematic study of relatively simple families of shapes may be accomplished through the use of just such a program component. It is obvious that the slab delta option could be replaced by a user-coded program component. This is illustrated in Figure 6. With this approach, a large number of shapes may be studied in a very short period of time.

The last component is the Card Punch routine. This option is provided in the Mark III program to permit the on-line punching of cards from the geometry storage tape. The use of this type of operation may not be possible on some other types of computers. In this case a different version of subroutine CARD is used that merely prints an on-line message to the computer operator that the geometry storage tape is to be saved and cards punched from it off-line.

Now that the general features of the Hypersonic Arbitrary-Body System have been introduced, it will be helpful to review each of the major system components in a little more detail.

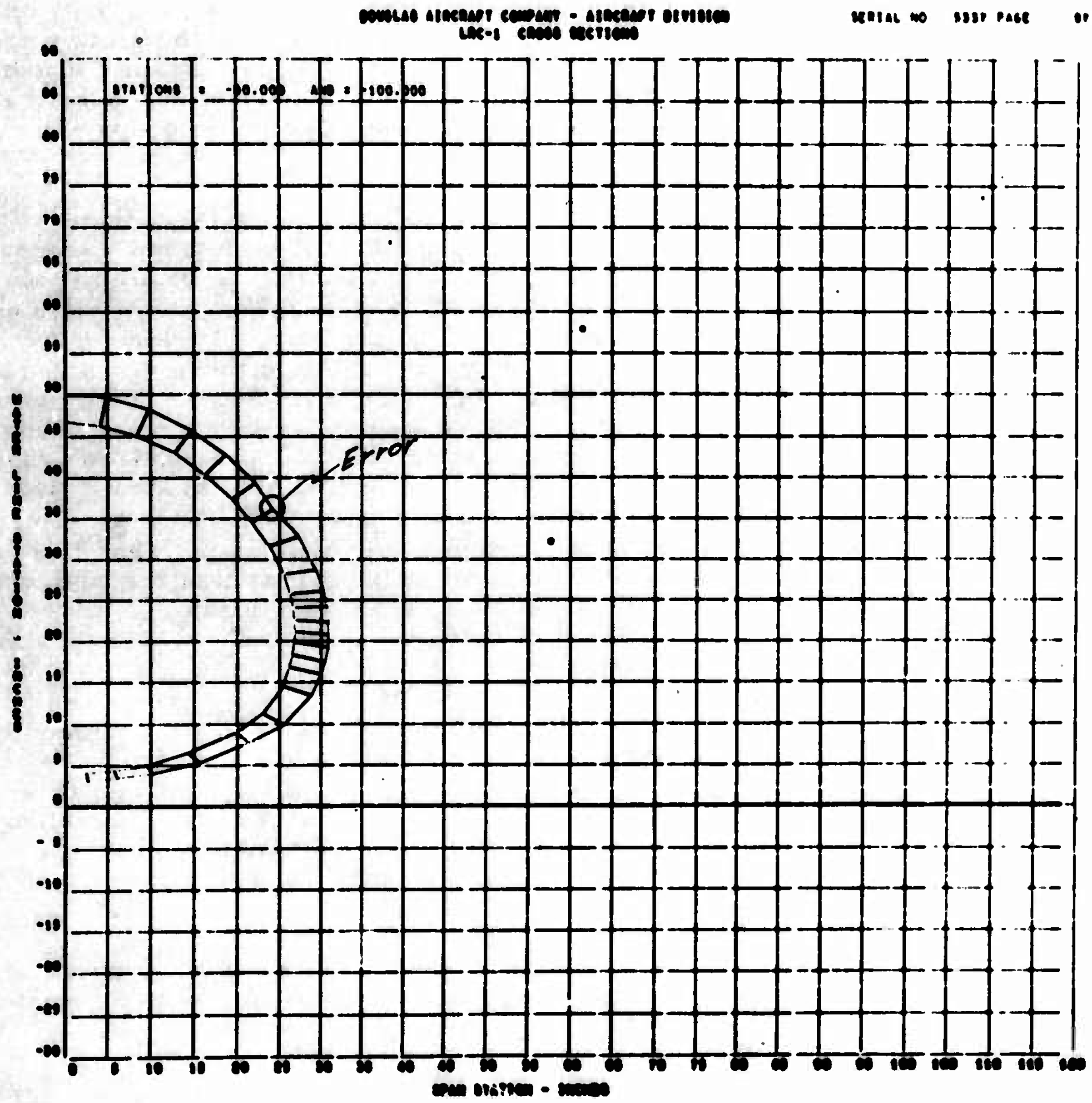


Figure 3. Perspective Drawing Cross-Section Output

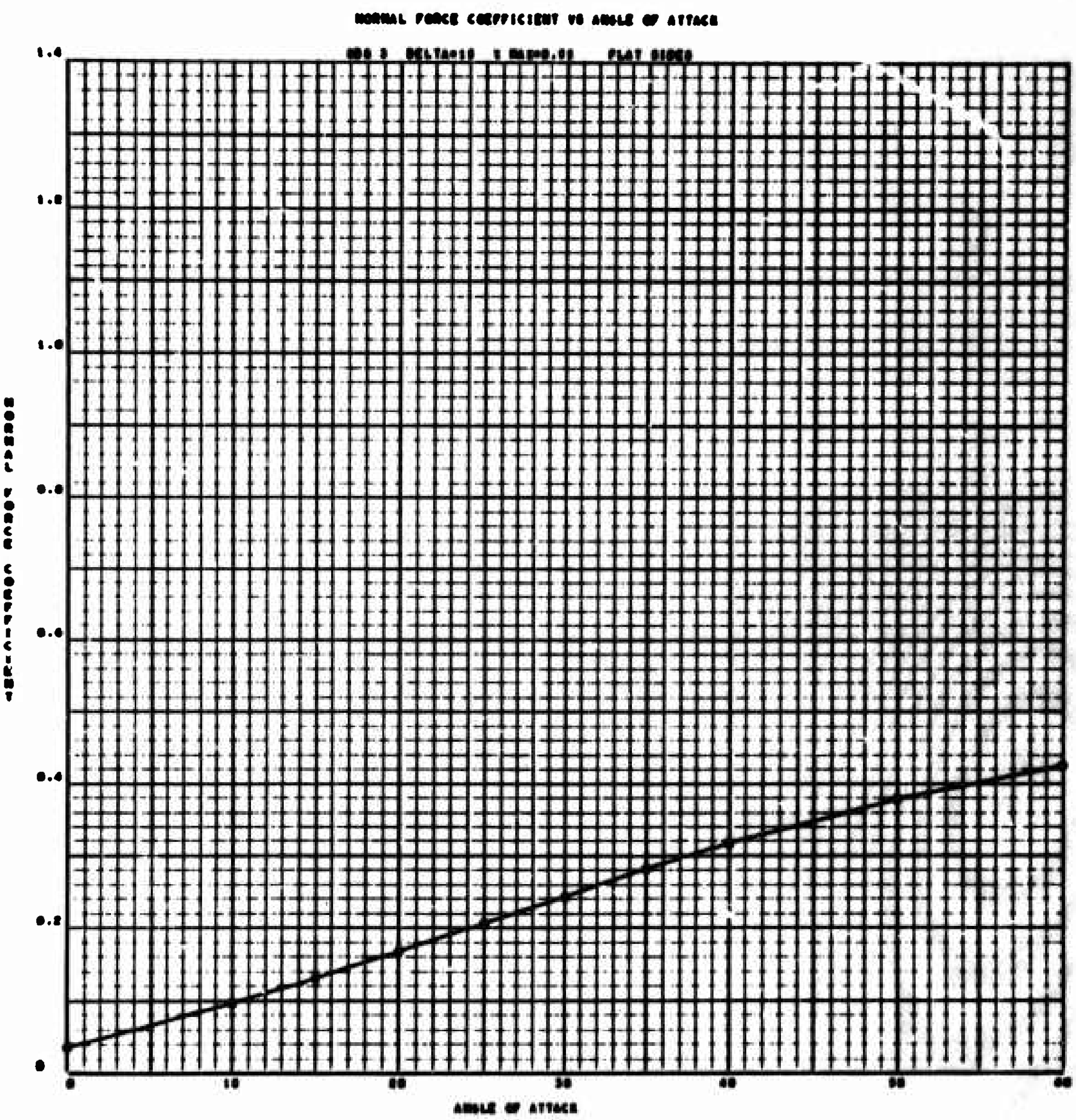


Figure 4. Curves from Output Data Plotter Program

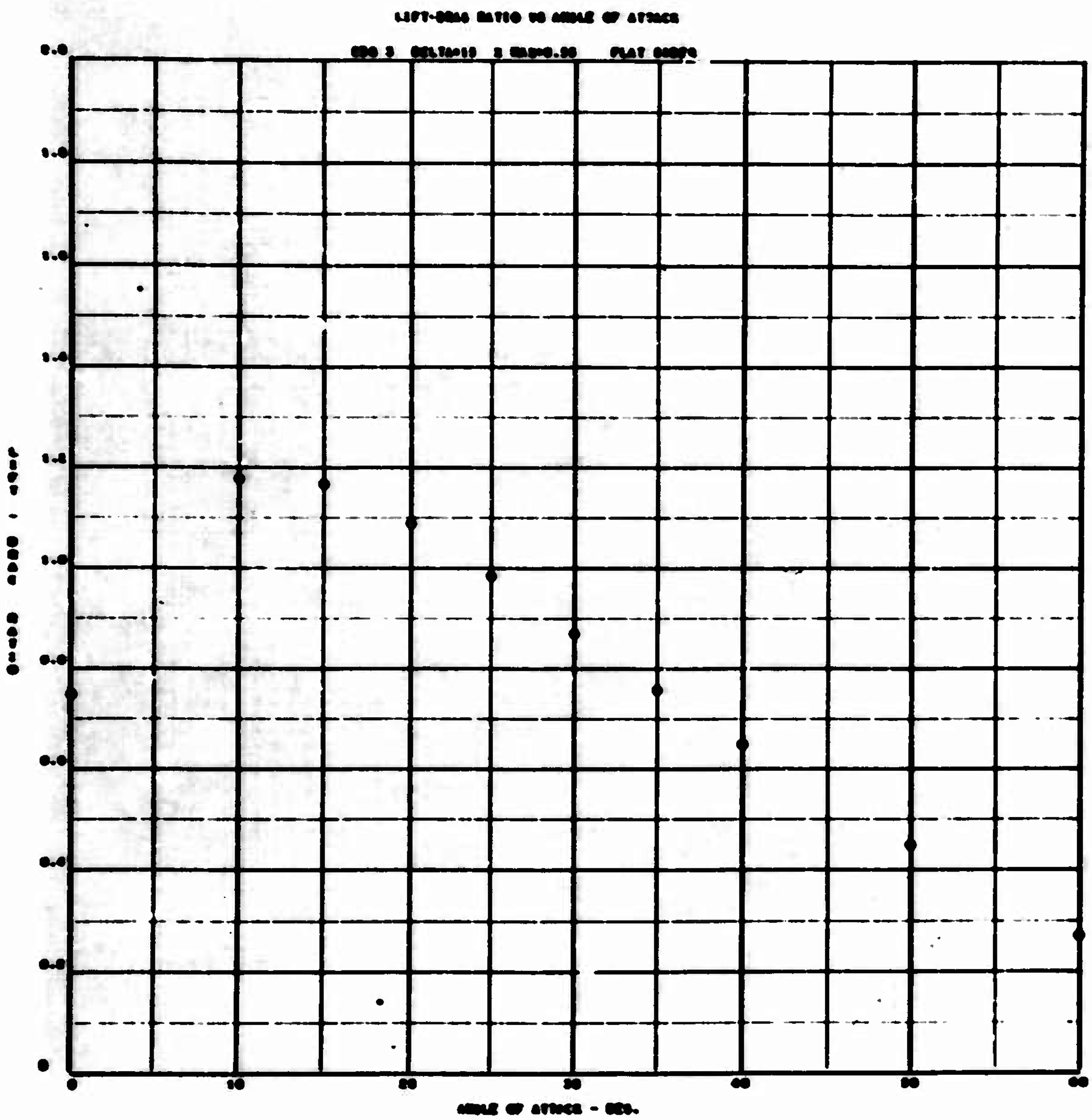


Figure 5. Curves from Output Data Plotter Program

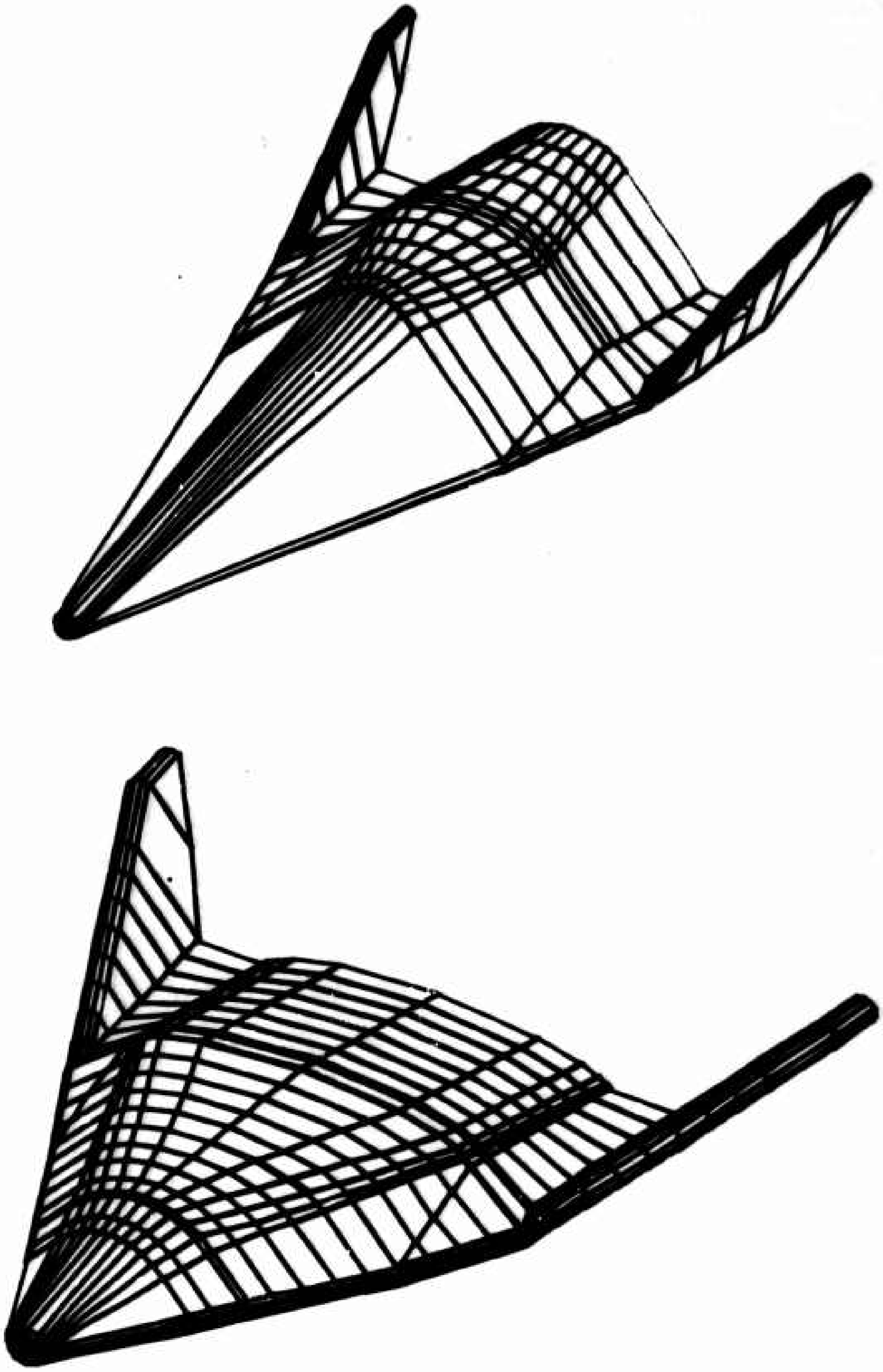


Figure 6. Configurations Generated by Separate User-Coded Program

AERODYNAMICS PROGRAM (AERO)

It is obvious that the AERO option is the major component of this system. The important features of the AERO program are its ability to handle any geometric shape, the availability in the program of a number of theoretical and empirical techniques for calculating the aerodynamic forces, and the capability of selecting different force-calculation techniques for different sections of the vehicle. With this concept, a vehicle may be represented by a number of geometric components, each component may be of arbitrary shape, and the most accurate force-calculation method may be used, depending upon the component or vehicle shape and the flight condition.

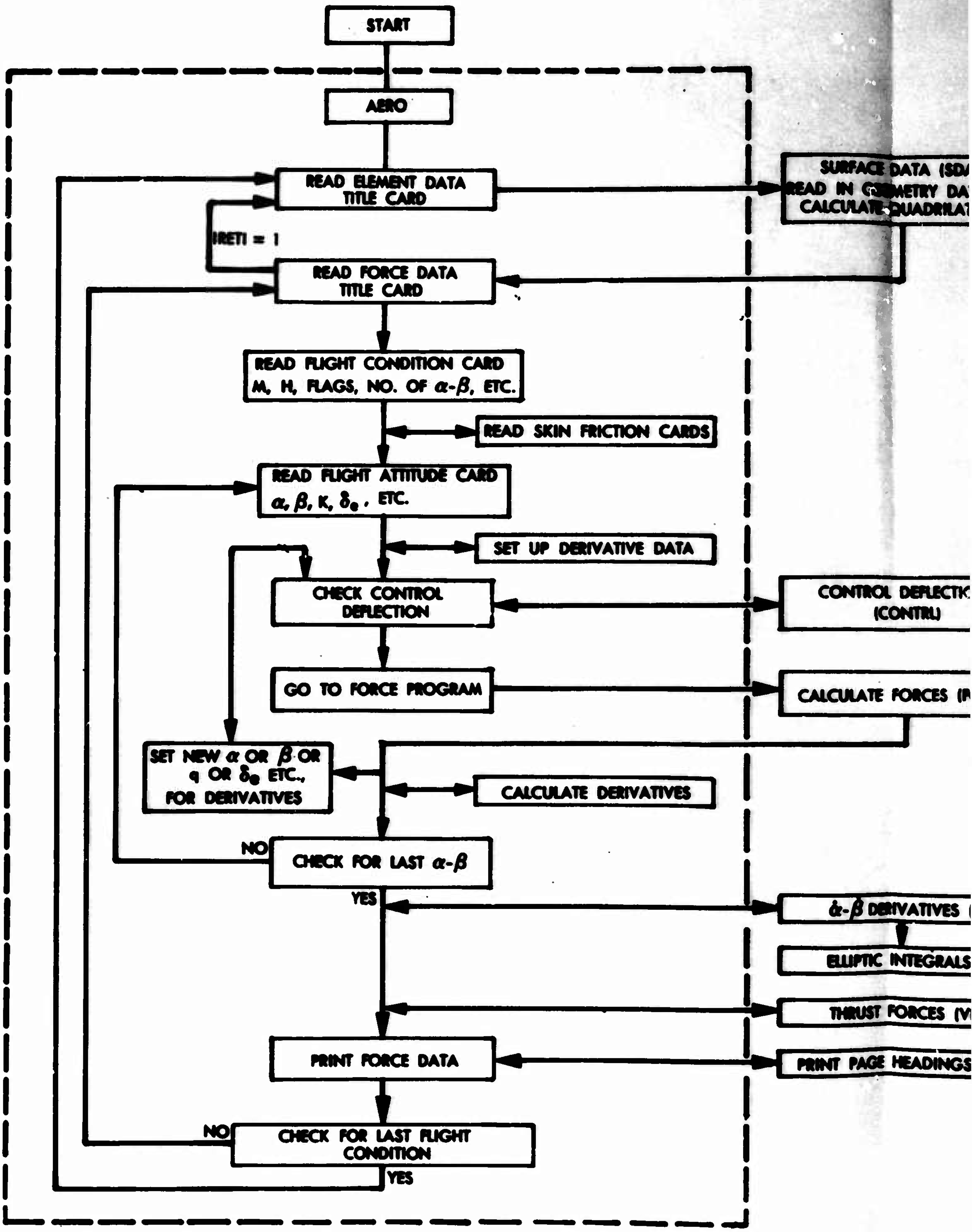
The AERO program contains all of the necessary components to allow the computation of the aerodynamic forces if the vehicle shape and desired flight conditions are given. The AERO program is written on a modular basis to faciliate checkout and rapid modification to meet changing needs. The program consists of a main program (AERO) that reads in input control data, controls the flow through major subprograms, and prints the output data. The organization of the major components is shown in Figure 7. Each subroutine shown in this figure provides a specialized function. The basic purpose and the operation of each subprogram are outlined below.

Surface Data Subprogram (SDATA)

The surface-data subprogram reads the input surface geometric data and converts it to a form used by the rest of the program. This operation consists of an organization of the surface data points (these are either input or generated within the program) into sets of four related points and then the conversion of each set of surface points into a plane quadrilateral element. The characteristics of each quadrilateral element are stored in the core (with the first 300 elements) and on a tape unit (with all the remaining elements). With this method there is no practical limit to the number of elements that may be used to describe a given arbitrary shape. The element characteristics that are stored for use in the force calculations include the element number (assigned consecutively), the direction cosines of the quadrilateral surface unit normal (directed outward), the coordinates of the centroid of the element, and the area of the element. If the user wishes, these characteristics may also be printed out for visual inspection. The surface areas of the quadrilaterals and the volume contributions are summed for each vehicle section and also printed out. This subprogram also provides any necessary scaling of the size of each input section and, if required, changes in the position of a section in the coordinate system.

The input geometry accepted by the SDATA subprogram may be in three different forms, as follows:

1. Surface Element Data – A large number of distributed surface points organized to form elements (either hand input or generated by the Slab Delta Program).
2. Analytical Shape Data for circular or elliptical cross sections (or portions thereof).
3. Parametric Cubic Geometry – Coordinates along each boundary curve of a surface patch.



START
AERO
READ ELEMENT DATA TITLE CARD
IRETI = 1
READ FORCE DATA TITLE CARD
READ FLIGHT CONDITION CARD
M, H, FLAGS, NO. OF α-β, ETC.
READ SKIN FRICTION CARDS
READ FLIGHT ATTITUDE CARD
α, β, K, δe, ETC.
SET UP DERIVATIVE DATA
CHECK CONTROL DEFLECTION
GO TO FORCE PROGRAM
SET NEW α OR β OR q OR δe ETC., FOR DERIVATIVES
CALCULATE DERIVATIVES
NO
CHECK FOR LAST α-β
YES
PRINT FORCE DATA
NO
CHECK FOR LAST FLIGHT CONDITION
YES
SURFACE DATA (SD
READ IN GEOMETRY DA
CALCULATE QUADRILAT
CONTROL DEFLECTIO
(CONTRL)
CALCULATE FORCES (F
α̇-β DERIVATIVES (
ELLIPTIC INTEGRALS
THRUST FORCES (V
PRINT PAGE HEADINGS

A

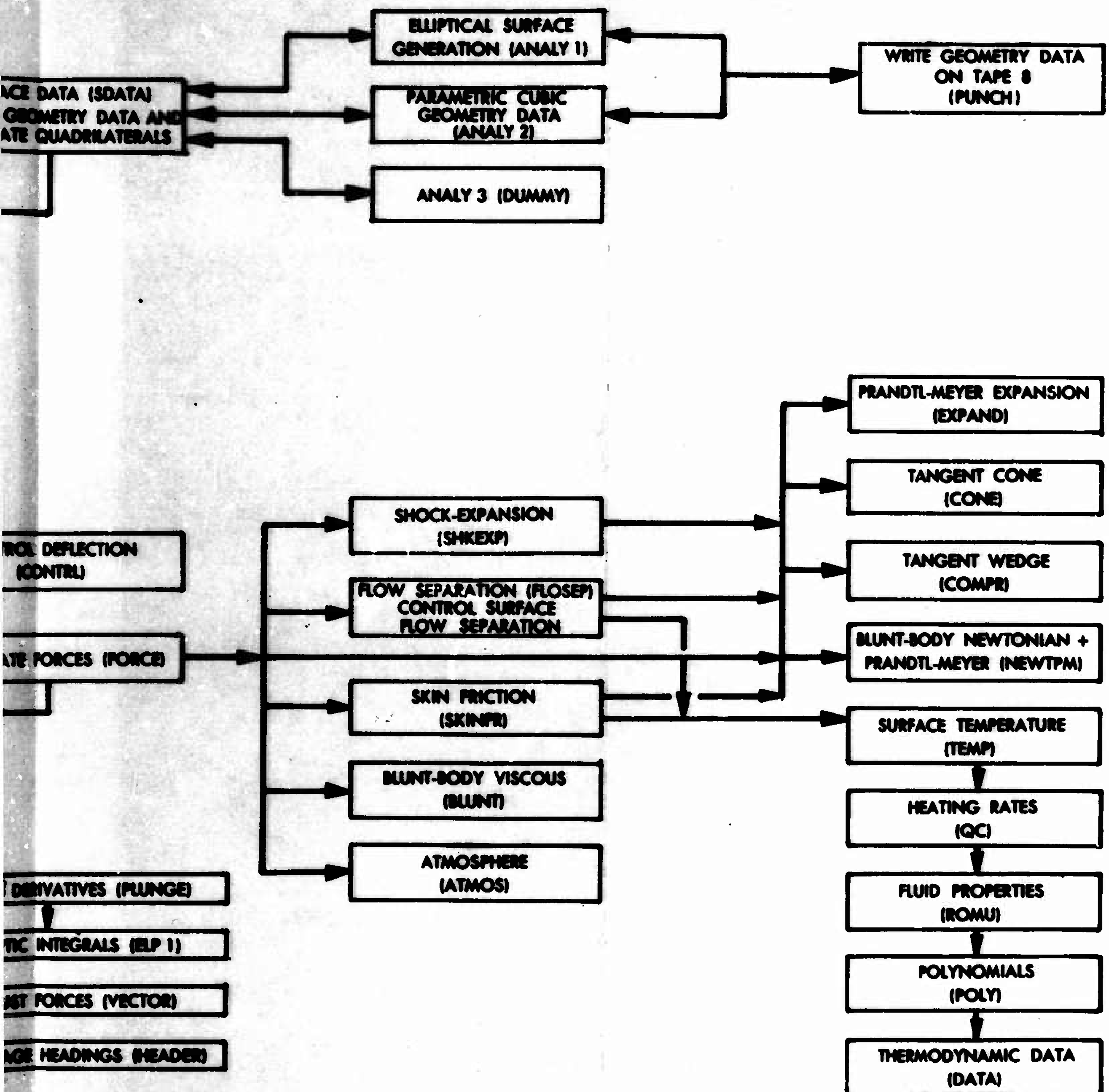


Figure 7. Aerodynamic Program Organization

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Regardless of the input method used, the geometry data are eventually converted into surface-element points before any further calculations are made. The conversion of elliptical geometry data or parametric cubic data into the required surface-element points is performed in separate subprograms. When surface-element data are generated by the Slab Delta Program, they are recorded on the geometry storage tape (Tape Unit 8). This is also true of element points generated either by the ellipse option or by the parametric cubic method. Once these data have been properly placed on Tape 8, they are in exactly the same form as regular surface-element input data. These data are then available for use in other parts of the program system. The tape on Tape Unit 8 may also be saved after a machine run, and regular BCD cards may be punched from it. On subsequent machine runs, these cards can be input directly as regular surface-element data. Provisions are also made for reading regular surface-element data from the standard input tape (Tape 5) and having these data transferred to the special geometry storage tape (Tape 8). From this very brief discussion we see that the proper management of Tape 8 will play an important part in the solution of many problems.

The techniques used in controlling the data on Tape 8 and the proper positioning of Tape 8 for each part of a problem will be discussed in more detail in a later part of this report. The most important aspects of the above discussion that the reader must remember are that, regardless of their original source, the geometry data must eventually be converted into the form of surface-element data before they can be used by the program. Once the surface-element data are available, they are converted into plane quadrilateral elements for subsequent computations. The use of Tape 8 is illustrated in Figure 8.

Elliptical Cross-Section Subprogram (ANALY1)

This subprogram prepares surface-element data points for circular or elliptical cross-sections. Any arc of a circle or ellipse may be formed at any given X-station, and the center of the curve need not be at the center of the coordinate system. With this subprogram, it is possible to generate, with a minimum of input information, the large number of surface points required for the quadrilateral calculations. This capability is most frequently used to generate data for vehicle nose sections, leading edges, and vehicle circular or elliptical cross sections.

Parametric Cubic Subprogram (ANALY2)

This subprogram accepts input geometry data in the form of coordinate points of surface-patch boundary curves. From these data it formulates an equation (parametric cubic) that describes the interior surface of the patch. Points on the surface are then calculated and the data stored on the geometry storage tape (Tape 8) in exactly the same form as regular hand input surface element data. The important feature of the parametric cubic geometry input method is that the size or number of elements generated to describe the patch is determined from just two input parameters. This method is used when it is desirable to frequently change the size of the surface elements, or when a large number of elements is required to describe a flat surface such as a control-surface flap.

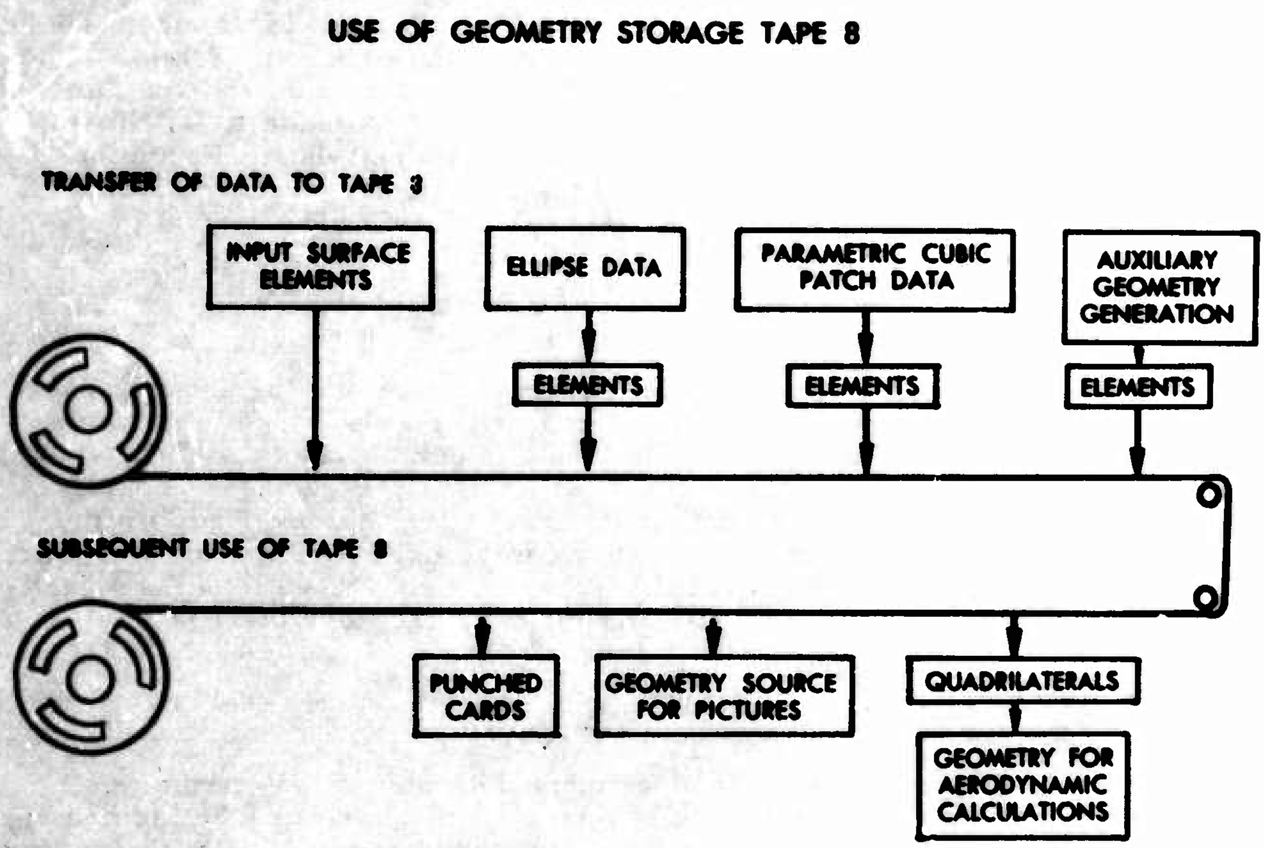


Figure 8. Use of Geometry Storage Tape 8

Analytical Shape Subprogram (ANALY3)

This subprogram is a dummy routine provided for possible future program modifications.

Control-Surface-Deflection Subprogram (CONTRL)

This subprogram has the task of converting input data for control-surface geometry in the undeflected position to any desired deflected position for subsequent calculations. The single important requirement for control-surface-geometry data is that the hinge line must be straight. The geometric characteristics of the control surface in the deflected position are stored on Tape 11. This subprogram also calculates and stores on Tape 11 the necessary hinge-moment length parameters for subsequent hinge-moment calculations. At all times during the program calculations, the geometric characteristics of the control surface in the undeflected position are maintained on Tape Unit 4. The geometry data for the area in front of the control surface (the fore-surface) are stored on Tape 3.

Force-Calculation Subprogram (FORCE)

This subprogram calculates the pressure coefficient on each quadrilateral element, resolves the force in the required body axis system, and sums the contributions of each element to give the vehicle's six aerodynamic coefficients. Some of the force-calculation methods require the use of another level of subprograms. The special subroutines provided include oblique-shock compression, Prandtl-Meyer expansion, Newtonian + Prandtl-Meyer, and flow separation. Several of these subroutines serve a dual purpose, since they are also used by the skin friction subprogram.

The force subprogram is organized in such a way that it is very easy to modify to include additional force-calculation methods. To facilitate modification, the logic in this part of the program has been kept as simple as possible with a minimum of cross-connection between methods. This simplified programming in the force calculation has been used even at the expense of a slight penalty in storage economy.

Header Subprogram (HEADER)

The header subprogram provides the title at the top of each page of the output and advances the page counter.

Atmosphere Subprogram (ATMOS)

This subprogram calculates the atmospheric properties for a given altitude by using U. S. 1962 standard atmosphere. This subprogram uses an inverse square gravitational field and gets results that agree with the COESA document within 1 percent at all altitudes up to 700 kilometers. The program is also capable of using input wind-tunnel conditions (stagnation pressure and temperature) to determine the properties of the free-stream air about a wind-tunnel model.

Flow-Separation Subprogram (FLOSEP)

This subprogram has the task of determining the effect of flow separation caused by the deflection of a control surface. The subprogram has all the necessary separation criteria built into it to provide the flow-separation point on the surface, the flow-reattachment position, and the change in vehicle surface pressures caused by the deflected flap and any resulting flow-separation effects. The flow-separation subroutine also makes use of data obtained from the shock expansion routine and the compression and temperature subroutines.

Shock-Expansion Subprogram (SHKEXP)

This subprogram is capable of performing a shock expansion analysis along a streamwise strip of elements. The local surface pressure, local flow Mach number, and temperature are calculated for each element. The calculation of a shock expansion along a given streamwise strip of elements starts with the determination of the flow properties on the first element in the strip (the section-leading-edge element). The local properties on this leading-edge element may be calculated either by oblique shock relationships, by tangent cone equations, by a delta-wing empirical method, or, in the case where the leading element is in shadow flow, by a Prandtl-Meyer expansion from free-stream conditions. The calculation of the properties on subsequent elements in a streamwise strip is based on a compression or Prandtl-Meyer expansion from the previous element in that strip.

Skin-Friction Subprogram (SKINFR)

This subprogram calculates the viscous forces with the option of using the Reference Temperature, Reference Enthalpy, or Spalding-Chi methods. The vehicle geometry is specified using the same methods as for the pressure calculation geometry model except that a smaller number of elements are used (usually less than 20). The wall temperature may be input to the program or the radiation-equilibrium value determined by the program. The local properties may be calculated by the tangent-wedge, tangent-cone, Prandtl-Meyer expansion, or by the Newtonian + Prandtl-Meyer method. The viscous-inviscid interaction effects are calculated by the method of White (Reference 3). The user may specify either laminar or turbulent skin-friction data to be added to the vehicle inviscid forces.

Blunt-Body Newtonian + Prandtl-Meyer Subprogram (NEWTPM)

This subroutine calculates the pressure coefficients on a surface by the blunt-body Newtonian + Prandtl-Meyer method. This subprogram is used both by the Force subprogram and by the Skin-Friction subprogram. Under oblique-shock detachment conditions, it will also be used by the oblique-shock compression routine.

This pressure-calculation method requires matching the pressure distributions calculated by the modified Newtonian and Prandtl-Meyer expansion methods at the point where their slopes are equal. In the blunt part of the

body before this matching point is reached, the pressure is calculated by modified Newtonian theory. When the surface slope has decreased beyond the matching-point slope, the pressure is determined by Prandtl-Meyer relationships.

Compression Subprogram (COMPR)

This subprogram calculates the pressure on a surface by using conventional oblique-shock relationships (NACA TR 1135). For conditions where no solution can be found for the oblique-shock cubic relationship (for shock detachment conditions) the compression subroutine will then call the Newtonian + Prandtl-Meyer routine in order to obtain a solution.

Expansion Subprogram (EXPAND)

This subprogram calculates the pressure on a surface by using Prandtl-Meyer relationships. The routine may be called by the Force Subprogram, by the Skin-Friction Subprogram, or by the Newtonian + Prandtl-Meyer Subprogram.

Temperature Subprogram (TEMP)

This subprogram uses an iterative procedure to calculate the radiation-equilibrium temperature on a surface for use in the skin friction calculations. Options also permit the use of an input wall temperature or the program determined adiabatic wall condition.

Convective Heating Function Subprogram (QC)

This subprogram calculates the aerodynamic convective heating at a given wall temperature for laminar or turbulent flow, and for either an ideal gas or a real gas. At the user's option, reference temperature or reference enthalpy methods may be used for both laminar and turbulent flow and, in addition, the Spalding-Chi turbulent method may be selected using either temperature or enthalpy ratios.

Polynomial Function Subprogram (POLY)

This program generates an N-th order polynomial and is used by ROMU in generating fluid properties.

Fluid Properties Function Subprogram (ROMU)

This subprogram calculates the various fluid properties of equilibrium air required for the real gas viscous calculations. The program has three entries; the first calculates the density-viscosity product at an input pressure and enthalpy, the second calculates the enthalpy corresponding to an input temperature, and the third calculates the density at an input enthalpy and pressure.

Block Data Subroutine

This subroutine initializes into labeled common "PROP" the coefficient arrays required by function ROMU to determine the real equilibrium air properties.

Cone Subprogram (CONE)

This subprogram calculates the surface conditions for a cone using empirical relationships. This routine is used by the force, flow separation, and skin friction routines when the tangent-cone option is called for.

Blunt-Body Skin Friction Subprogram (BLUNT)

This subroutine calculates the viscous forces on a blunt faced body. This routine is used by the Force subprogram in a mode similar to the inviscid pressure calculation options. The vehicle forces calculated, however, account for only the blunt-body skin friction shear forces and should be added to previously calculated inviscid forces using the data summation option.

Plunge-Derivative Subprogram (PLUNGE)

This subprogram is used to calculate the dynamic-stability derivatives due to vertical acceleration ($C_{m_{\dot{\alpha}}}$) and horizontal acceleration ($C_{Y_{\dot{\beta}}}$). This is essentially a separate auxiliary subprogram that is used to calculate these special derivatives by conventional analysis techniques. The subprogram includes the calculation of the conventional interference factors for the effect of a wing in the presence of a body and the interference factor for the effect of a body in the presence of wing. The computations for $C_{m_{\dot{\alpha}}}$ involve the application of slender-body-theory results to the value of C_{m_α}. This is also true of computations for the parameter $C_{Y_{\dot{\beta}}}$, where the Plunge Subprogram must make use of the parameter C_{Y_β} as calculated by the Arbitrary Body Program for the vehicle component involved. Since a particular body may consist of several different components, each of which may have been analyzed separately, it is necessary to wait until the final values of these two parameters (C_{m_α}, C_{Y_β}) have been obtained.

It is for this reason that the Plunge Derivative Subprogram should not be called until the user indicates that the necessary vehicle-component computations have been completed, and that he finally wishes the plunge derivatives to be calculated.

Elliptical-Integral Subprogram (ELP1)

This subprogram is used by the Plunge Subroutine to approximate the values of the elliptical integrals of the first and second kinds.

Thrust-Vector Subprogram (VECTOR)

This is also a utility subprogram. It may be primarily used to introduce propulsion-system effects into the aerodynamic analysis. This subroutine reads in input data that give the magnitude of each applied force vector, its direction, and its point of application on the vehicle, relative to the center of gravity. The subprogram will then convert this information into the required force and moment coefficients for summation with the basic vehicle characteristics. To make the solution more general, any number of input force vectors may be used to account for such things as ram drag, gross thrust, spillage, and other similar forces or moments.

GRAPHICS PROGRAMS (GRAPIC)

The graphics part of the system has two components – the Picture Drawing Program (PICTUR) and the Output Data Plotter Program (PLOT). Each of these options is actually a separate individual program that has been combined under the Executive Control Program to increase system flexibility. If required, each could be removed from this system, and with only a few minor modifications, operated as an independent program.

Picture-Drawing Program (PICTUR)

The Picture-Drawing Program is a very important component of the Hypersonic Arbitrary-Body System. Its use in this system is in providing graphical drawings of the geometric description input to the Arbitrary-Body Force Program. The purpose of these drawings is to allow the engineer to detect errors in the geometric input data.

The input geometry data are sets of points in three-dimensional space. A grouping of four surface points is used to describe a surface element. An aggregation of a large number of related surface elements forms a body section, and a number of sections may be used to give a complete description of the shape. These data are converted by the Picture Drawing Program into a form usable by the SC-4020 automatic plotter. This is accomplished by a transformation of the vehicle surface points with the required rotation matrices to give the desired viewing angle. The SC-4020 then draws straight lines between the corner points of each element on a special cathode-ray tube. The image is then photographed.

The unit normal for each element is also transformed with the rotation matrices and the resulting component out of the plane of the paper calculated. If the component is positive, the element faces the viewer and is, therefore, drawn by the computer. If the component is negative, the element faces away from the viewer and the element is not drawn. This procedure yields very realistic drawings of the vehicle from any desired viewing angle and serves

both to check the geometry data for errors and to illustrate the method used in describing the shape for the computer. The resulting picture is thus made more realistic, and confusing elements on the back side of the vehicle do not appear. No criterion is provided, however, for the deletion of those elements that, though facing the viewer, should be hidden by some other body component. Only a very careful selection of viewing angles or a physical deletion of the offending section from the input data can delete these elements. As a last resort, they can be removed from the picture by hand.

Output Data Plotter Program (PLOT)

The Output Data Plotter Program is used to produce graphically plotted data as obtained from the aerodynamics part of the program. This program may also be removed from the Hypersonic Arbitrary Body System and operated as an independent program. The program has the capability of reading the data to be plotted, either from the standard system input tape (Tape 5) or from the special aerodynamic-characteristics tape generated by the AERO part of the system. It is also possible to mix these two modes of operation on one plot, which is useful in comparing program-calculated characteristics with test data. In this version of the Hypersonic Arbitrary Body System, twelve vehicle characteristic variables may be saved by the AERO Program for subsequent plotting by the PLOT routine. These variables are α, C_D, C_L, C_A, C_Y, C_N, β, L/D, C_m, C_ℓ, C_n, C_f.

If the user requires other variables to be plotted, he may accomplish this by making a minor modification of the portion of the AERO Program involved with saving characteristics data on the AERO Plot tape.

SLAB DELTA PROGRAM (SLABD)

The Slab Delta Program is included in this system to illustrate the analysis of special analytical shapes by the system. Its basic purpose is the formation of the appropriate geometry data from a minimum of input data. This provides the capability of studying a very large number of simple shapes with a minimum of effort. In many applications it would be possible to make minor modifications of the Slab Delta Program to permit the analysis of some other family of simple shapes. A picture of a vehicle generated by the Slab Delta Program is shown in Figure 9.

CARD PUNCH PROGRAM (CARD)

This part of the Arbitrary-Body System is used to produce punched cards of the data that has been placed on the geometry storage tape (Unit 8). This option is used on those computers that produce card output in a direct on-line mode by writing the information on the standard punch unit (Unit 7 on the IBM 360 computer). This capability may not be available on some installations. If this is the case the geometry storage tape (Tape 8) must be saved after a job and any required cards punched off-line by a tape-to-card device.

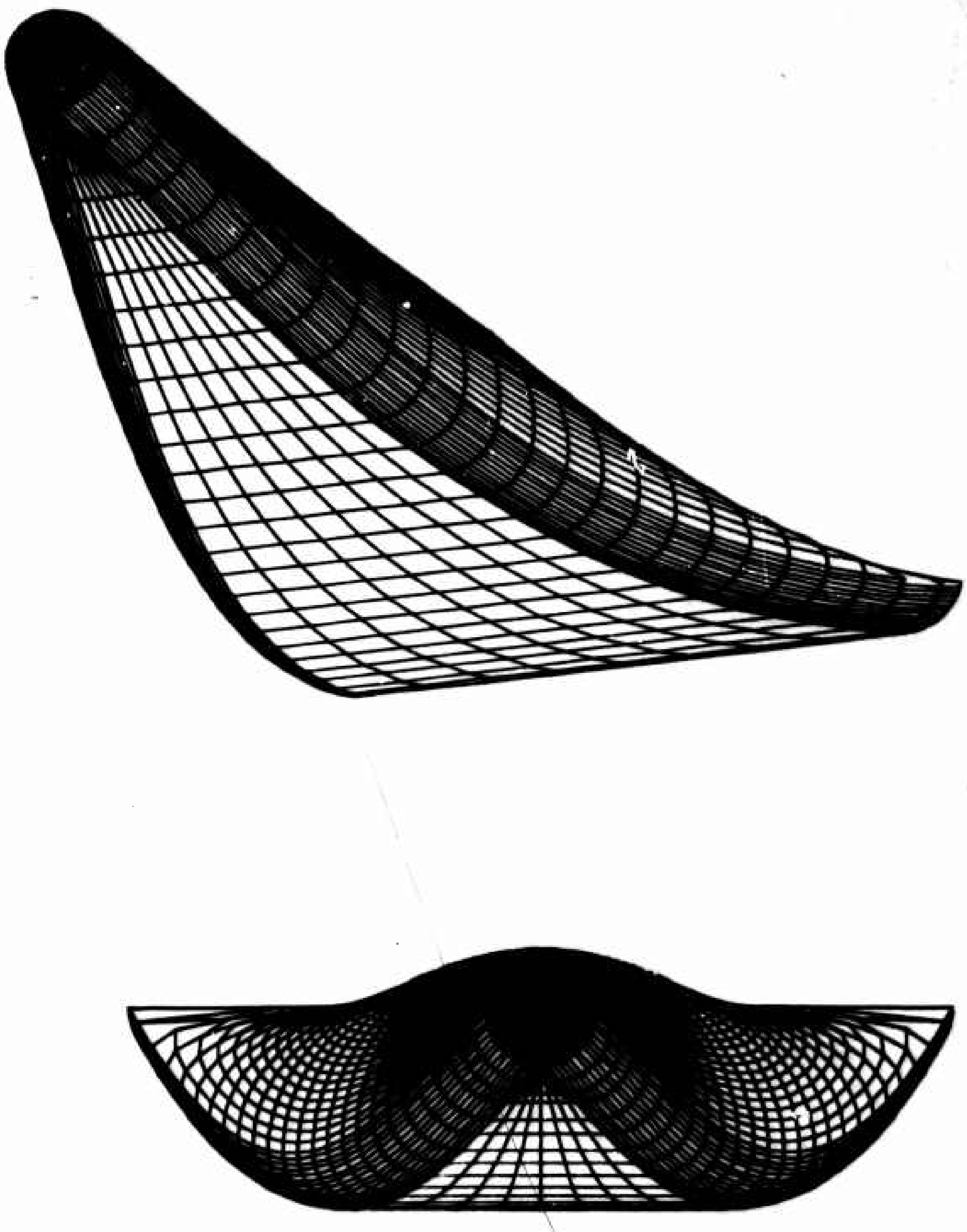


Figure 9. Geometry Data Generated by Slab Delta Program

PHILOSOPHY OF PROGRAM USE

As can be seen from the system diagram on page 9, the Executive Program has the task of controlling the flow to and from each of the four major program options. It accomplishes this with a single input card, the first card in the data deck. The user enters numbers in this card to identify the program components to be executed and the order of their solution. This is best demonstrated by the use of a sample problem. A complex problem will be intentionally selected, to give the reader a better understanding of the full capability of the program. Throughout each step of this example, the reader will find it helpful to trace the program flow on the system diagram on page 9.

In the example it will be assumed that the user wishes to generate a slab-delta vehicle with a lower surface flap (see Figure 10), calculate the aerodynamic characteristics, obtain pictures of the configuration used, obtain plotted output of the resulting aerodynamic characteristics, and reenter the aerodynamic part of the program with a complete new set of geometry data for a second, different vehicle shape. He then wishes to calculate the aerodynamic characteristics of the second vehicle, draw pictures of it, and then have the final characteristics plotted.

The first step in this rather complex problem is to prepare the geometry data for the slab-delta configuration, including the control surface. The first program option selected by the user is the Slab Delta option. By inputting the appropriate option flag, the Executive Program first goes to the Slab Delta Program option, reads in necessary input data to this option, prepares geometry data for the desired part of the slab delta (for example the nose section of the slab delta), and places this geometry information on the geometry storage tape, for use by the other components of the program system. Control is then returned to the Executive Program.

The next option flag directs the flow calculations into the AERO part of the system. In this program phase the remaining geometry components are input or formed by using a combination of input element data, ellipse-generation capability for the leading edges, and parametric-cubic-geometry method for description of the flap surfaces. At this point in the problem, the entire vehicle geometry (including nose, aft leading edges, and flap surfaces) has been recorded on the geometry storage tape and is available for calculations or for subsequent drawing of vehicle pictures. While in the AERO option, aerodynamic characteristics are also calculated. After this is completed, the program control is returned to the Executive Program.

For the next phase, the Executive Program sends control to the Graphic section of the program and then to the Picture Drawing option. The Picture Drawing option reads the necessary plotting information, reads the geometry data from the geometry storage tape, and, with the use of the SC-4020 system, writes on a special output tape that will eventually be processed on the SC-4020 automatic plotter to give realistic pictures of the vehicle. When this is completed, the control is again returned to the Executive Program.

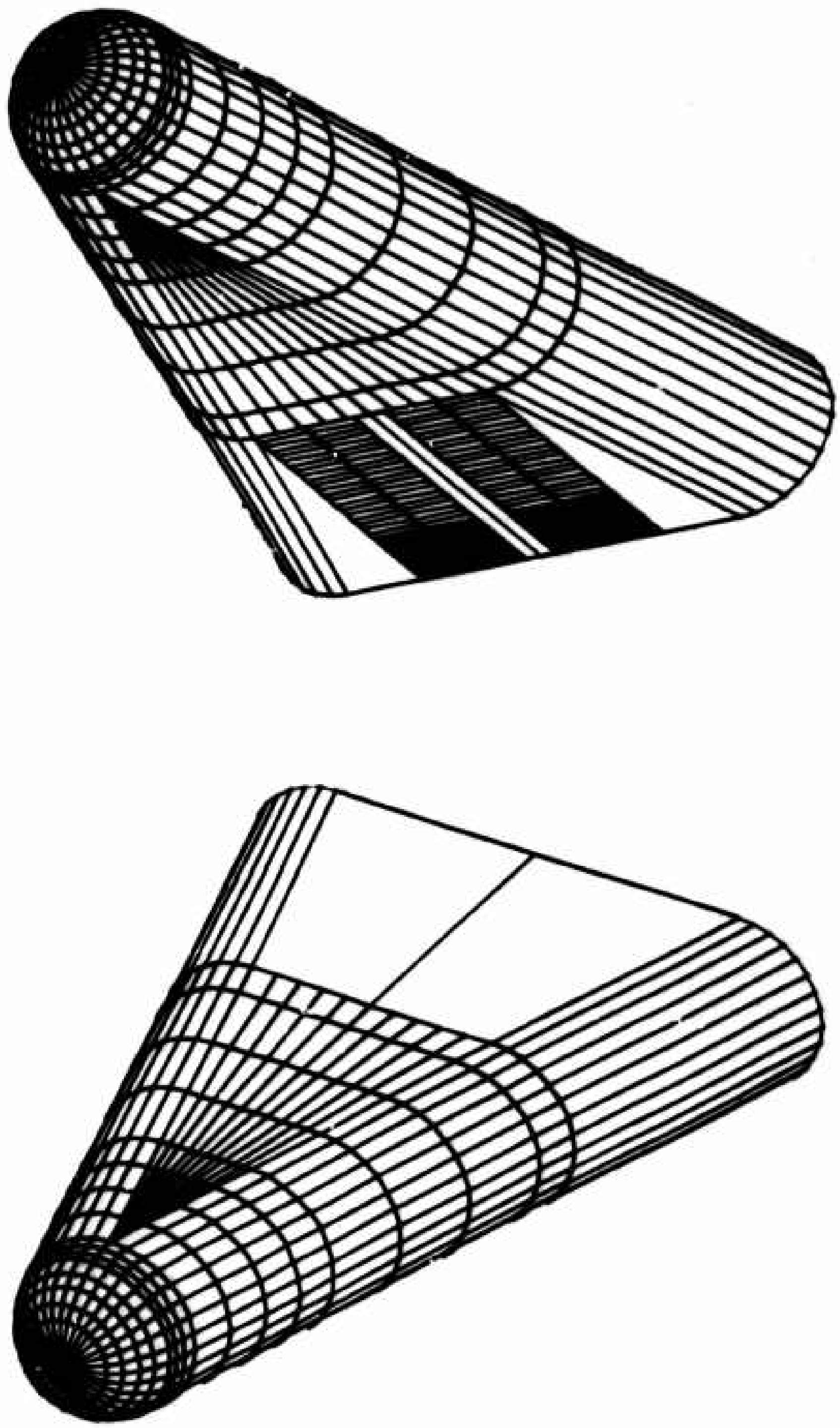


Figure 10. Geometric Representation of Slab Delta Configuration

For the next phase, the Executive Program again turns control over to the Graphic Program and then to the Output Data Plotter Program option. In this option, picture-scale information is read in, the aerodynamic characteristics read from the aero-characteristics storage tape, and final plotting information placed on the SC-4020 tape for subsequent processing off-line. When this is completed, the program returns control to the Executive Program.

At this point in our example, the first problem involving the slab-delta configuration has been completed. But the machine run is not completed, since the user wishes to read in a completely new set of geometry data for a different vehicle, calculate the aerodynamic characteristics, draw pictures, and plot the aerodynamic characteristics. To accomplish this, the Executive Program again returns control to the AERO option. Here, the geometry data are read into the program, saved on the geometry storage tape, the aerodynamic characteristics are calculated and saved on the aero-characteristics plot tape, and the control is returned to the Executive Program. The Executive Program then sends control to the Picture Drawing Program, which, after completing the pictures again, returns control to the Executive Program. Finally, the Executive Program calls upon the PLOT option to prepare final plotted data. Since no more data are to be calculated, or pictures to be drawn, or data to be plotted, the Executive Program congratulates the user for having successfully completed his problem, and pronounces the job finished.

Up to 20 different phases may be used on any single machine pass, and, from the above example, we see that it is permissible to enter any program option more than just once.

By studying the above example, the user should be able to gain an understanding of the general purpose and use of the Executive Program and of the effective use of the various components of the system in combination to accomplish even the most complex analysis task.

One warning should be made regarding the use of this computer program. The program contains a large number of user options, the most important of which is the selection of the method to be used to calculate vehicle pressure. The program makes available a number of different methods that cover a wide variety of shapes and flight conditions. It is obvious that a random or hasty selection of the pressure method is apt to give misleading or even completely erroneous results. The user should not get the feeling that this big and complex program is suddenly going to perform miracles — it won't. All the program does is place at his disposal a collection of analysis tools. The kind of tool that he selects for a particular problem (such as geometry-description method or pressure-calculation method) will determine the validity of the answers produced.

When none of the methods available in the program are suitable for a given problem application then a new method must be derived and added to the program. The difficulty in accomplishing such additions depends upon the specific requirements of the problem. If a new pressure calculation method to be added is as simple as a new empirical equation for pressure as a function of local impact angle and flight condition, then the modification can be

accomplished very quickly. If the new method requires some other information about the characteristics of the shape or the flow field (like the shock-expansion method already in the program), then the modification would be more difficult and would require a more intimate knowledge of the details of the program.

APPROACH TO PROBLEM SOLUTION

Before attempting to use this program for the first time, the user should read the entire manual. Obviously, the purpose of the first reading should be simply to get a rough idea of the general contents, not to make a thorough study of the input instructions. The user will then have to decide exactly how he is to attack his problem. The first step involves a decision as to how the various components of the system are to be used. This will require the use of a thinking process similar to that described in the Section entitled Philosophy of Program Use and further illustrated in later sections of this report.

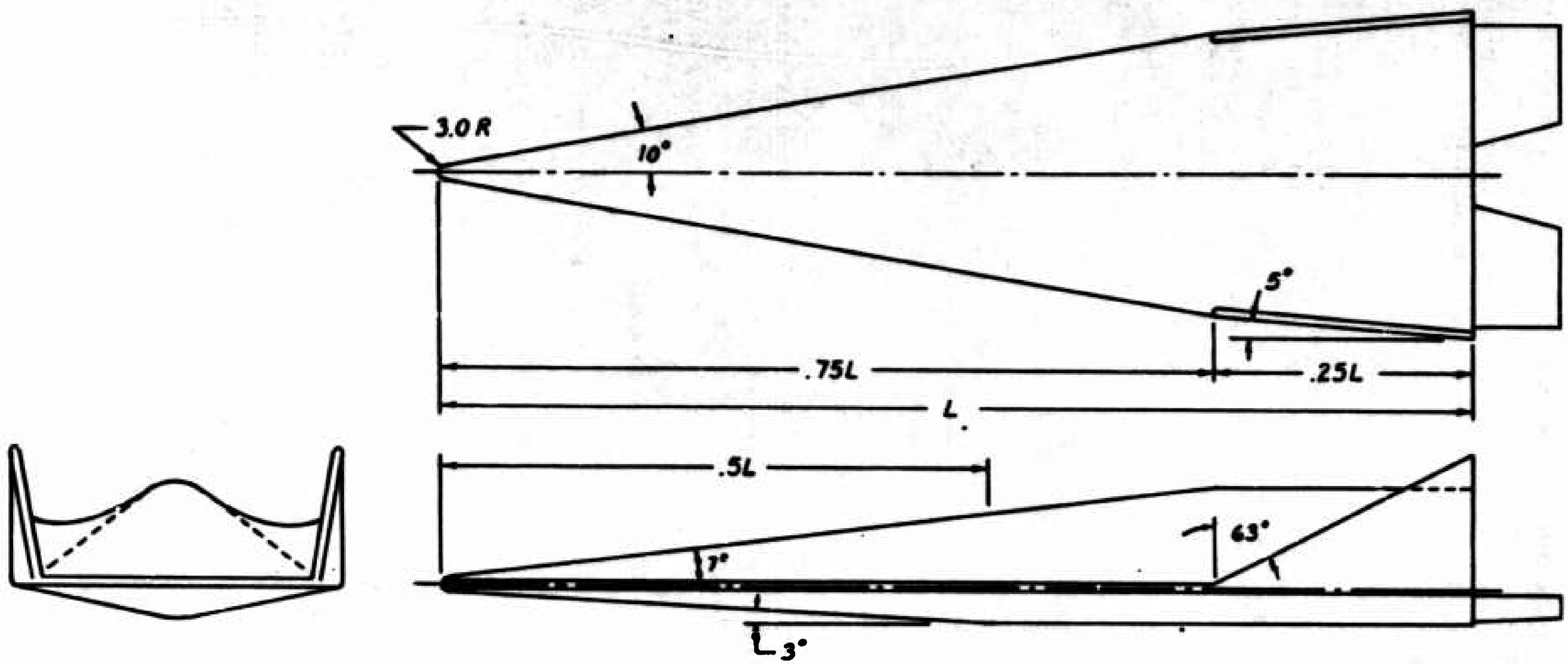
Once the user has decided how he is to make use of the AERO Program, the Picture Drawing Program, the Output Data Plotter Program, and any auxiliary geometry program such as the Slab Delta Program, he may proceed with the detailed preparation of the geometry data.

GEOMETRY DATA PREPARATION

The original geometry data available may take several forms. A simple three-view dimensioned drawing of the vehicle is the most common form. A front view of the shape with a number of cross-section cuts is also required. The latter drawing should be on grid paper, to enable the reading of the X, Y, Z coordinate data. A set of drawings for a typical reentry vehicle design is shown in Figures 11 and 12. Figure 12 is a good example of the amount of cross-section data required for most problems.

The Hypersonic Arbitrary Body System provides several different options for use in describing a given shape. First, the geometry can be described completely external to the AERO program by the Slab Delta Program. Or, the geometry can be obtained from a user-coded program in place of the Slab Delta routine. This approach can be used when a large number of very simple shapes are to be studied.

Most of the time, however, the user will avail himself of the options provided within the AERO program. The three techniques provided are (1) input element data, (2) ellipse cross-section generation data, and (3) parametric cubic patch data. The selection of the method will usually depend upon the shape of each component of the vehicle involved, and sometimes on the pressure-calculation method to be used. Obviously, nose sections of a vehicle and leading edges should be generated by the ellipse option. Other elliptical or circular portions of a vehicle can also be generated in this manner. Complex curved surfaces can be described either by the element-data method or by the parametric-cubic-patch technique. After experimenting with each, the user will form an opinion as to which method he finds easiest for his type of application.



CASE 19

Figure 11. Three-View Drawing of Typical Re-entry Vehicle

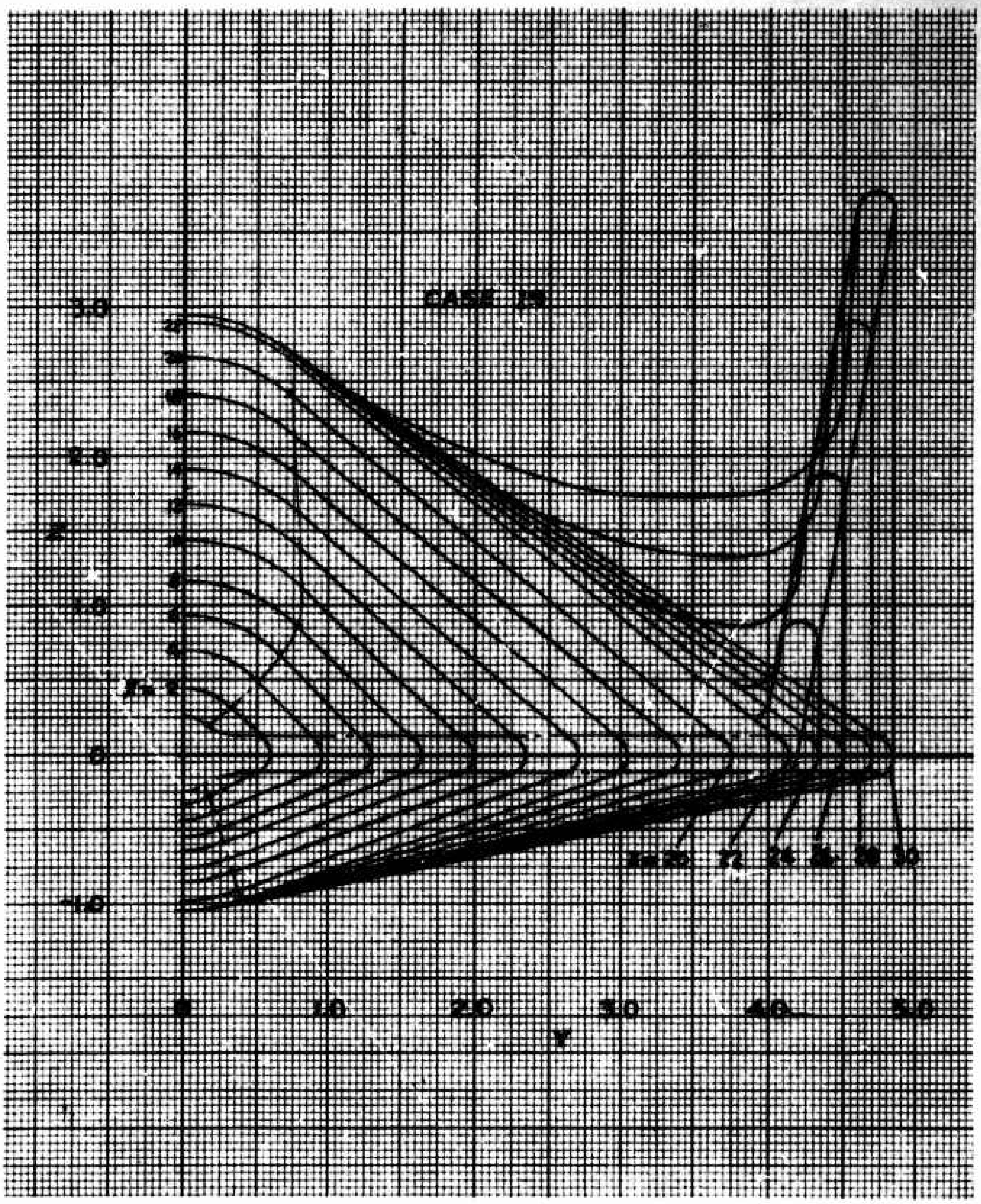


Figure 12. Cross-Section Data Used to Describe Case 19

In working with conventional cross-section data, it will be found that the surface-element method is the easiest technique to use, even though it usually requires more input data. The reason is that only one coordinate plane need be considered, say the Z, Y plane, with the other coordinate (the X-station) held constant for a given vehicle cross-section cut. In the parametric cubic method, the user must work in the cross-section plane and at the same time must also record patch boundary-curve coordinates in the longitudinal (X-station) direction.

The parametric-cubic method becomes useful when a large flat portion of a vehicle must eventually be available to the program with a relatively fine-mesh network of surface elements. This would apply to control-surface flaps and to that portion of the vehicle in front of the flap, upon which separation effects are to be investigated.

With the foregoing knowledge of the various geometry methods, the user will be able to formulate a general approach to his particular vehicle shape. He will first divide the vehicle into a number of logical components or sections.

The division should be based not only on the physical character of the shape but also on the requirements to use different pressure-calculation methods on different parts of the vehicle. The method of preparing the geometry data for each component is then selected. A typical application will usually involve some geometry data loaded by hand, by using the surface element or the parametric-cubic methods, and some data (such as nose and leading-edge components) generated by the internal elliptical-surface-generation routine with a minimum of input data.

In the example presented in Figures 11 and 12 it was decided to describe the vehicle nose, body leading edge, and vertical-fin leading edge with the ellipse-generation option. The rest of the vehicle was described by using the surface-element input method. The final representation of the vehicle is shown in Figures 13 and 14.

Before proceeding with this discussion, several important (and often confused) geometry terms should be defined.

Surface Element:	This, the smallest geometry unit, consists of four related points on the surface of the vehicle and the area enclosed by lines connecting successive points. All geometry data must eventually be made available to the program in surface-element form.
Plane Quadrilateral Element:	Each surface element is converted by the program into a plane quadrilateral element. The plane quadrilateral element is the basic geometric unit used in the force calculations. This unit, in effect, is the integration step size and is fixed once the surface element representation of the shape is established.

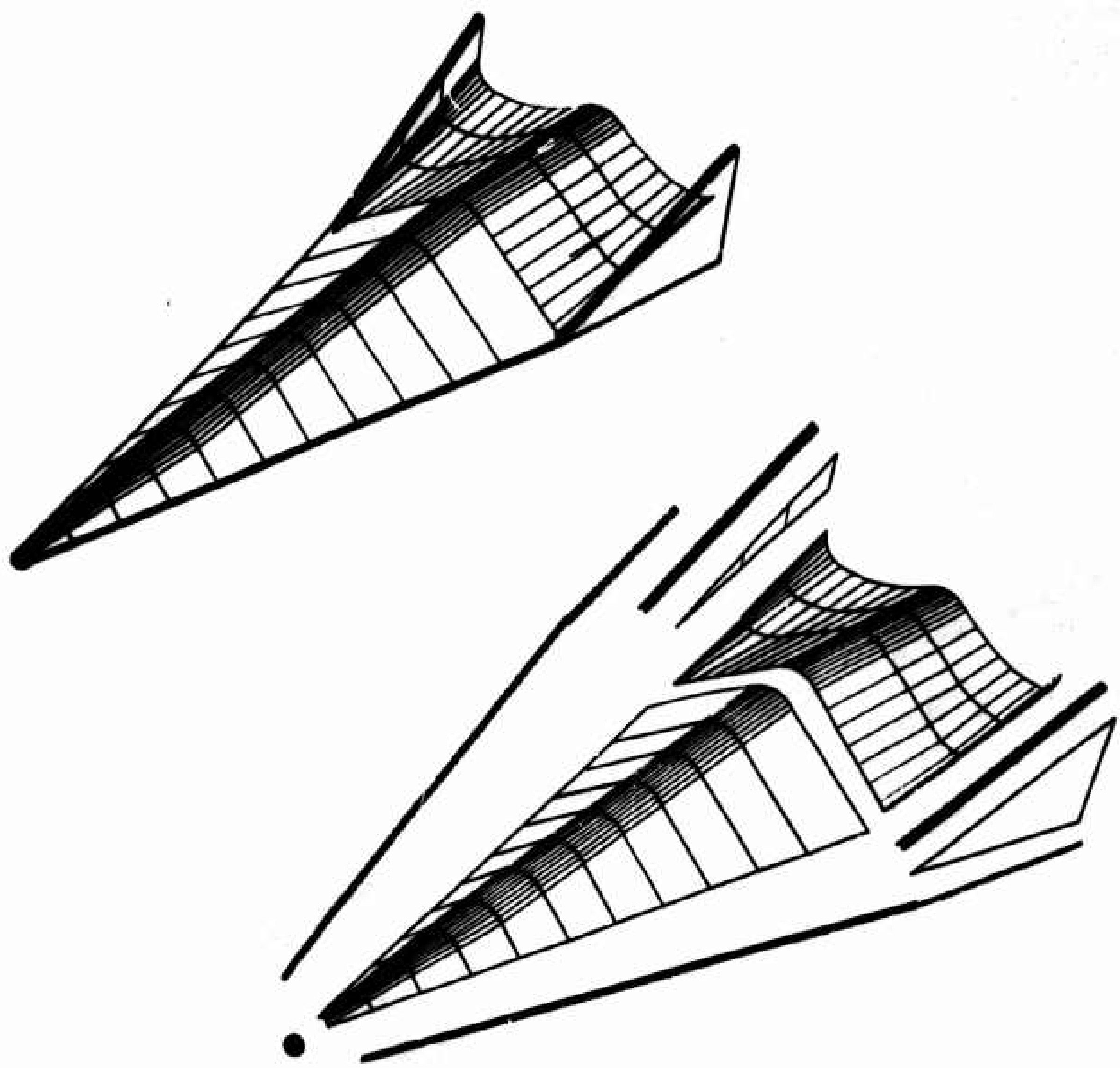


Figure 13. Geometric Representation of Re-entry Vehicle Shape

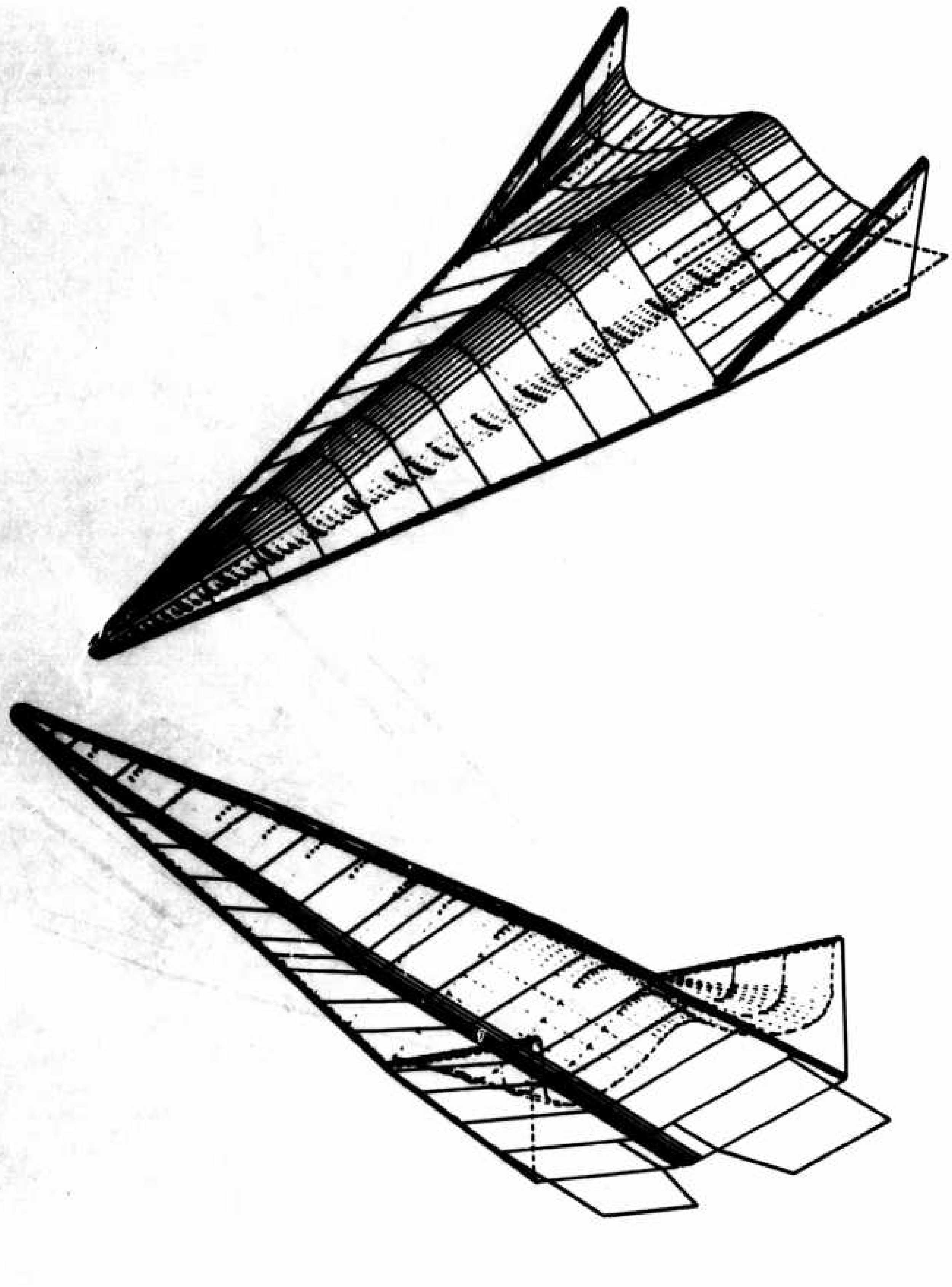


Figure 14. Geometric Representation of Re-entry Vehicle (With All Vehicle Surfaces Drawn)

Cross-Section Cut: A cross-section cut is that view obtained by cutting the vehicle in the longitudinal plane (Z, Y plane), at a constant X-station.

Vehicle Section: A vehicle section consists of an aggregation of surface elements that have similar size and proportions. In general practice, the vehicle section is selected first, and then the section is divided into a number of smaller units called surface elements. Do not confuse the word "section" with the word "cross-section."

Vehicle Component: A vehicle component is usually thought of as being a major portion of the vehicle, such as body, wing, or tail. In this program a component is defined as being a part of the vehicle over which the user wishes to use one given pressure-calculation method. The term "component" is also used to define a portion of the vehicle that the user wishes to be analyzed as a separate unit (i.e., to provide information on the contribution of each part of the vehicle to the overall characteristics). A component may consist of one or more vehicle sections.

Parametric Cubic Patch: A parametric cubic patch is a portion of the vehicle surface to be described by the parametric-cubic method. Input data to the parametric-cubic method consist of coordinates along the four boundaries of a surface patch. The program converts the patch to a number of surface elements, as specified by the user. The resulting set of surface elements constitutes a vehicle section (it is also possible to combine several patches to form a single section).

After the user has divided the vehicle into a number of vehicle sections, he will find it helpful to identify each section by a letter or number. Many users then color the cross-section drawing, using a different color for each vehicle section. This helps to prevent confusion in reading the coordinates of points in each section and reduces the number of reading errors. For some portions of the vehicle, such as leading edges and fillets, larger scale cross-section drawings may be useful.

The coordinate system used in recording geometry data is shown on page 86. Throughout this manual, the definitions of left and right and up and down are based on the assumption that the user is sitting in the vehicle and facing forward. The conventional approach is to always input geometry data for the left side of the vehicle only (providing the vehicle is symmetrical about the X, Z plane). It is also standard practice to have the nose of the vehicle at the center of the axis system, with the vehicle extending aft in the negative X-direction. Although the program is general, in that other loading techniques may be used (i.e., base of the vehicle at the center of the coordinate system and the nose at some positive X-value), maximum benefit can be gained from the descriptions and examples in this manual if the above procedures are used.

The process of loading the geometry data may vary from a short 10-minute job for a very simple shape, to as much as 2 or 3 days for a very complex arbitrary shape being loaded completely by hand. Because of the simplicity of the input surface data (X, Y, Z coordinates only) it is possible to apply a semiautomatic data reading system to completely overcome the problem of reading and recording the large number of surface points required to describe a very complex shape. Several data-analysis-equipment manufacturers produce models of X-Y reader-recorder equipment suitable for this purpose.

Regardless of the time required to prepare the geometry data, the user should realize that, once the data are read, he may perform many subsequent analysis studies with this shape by inputting to the program only the necessary program control data.

The preparation of input geometry data, the necessary AERO program control data, and the subsequent production of vehicle pictures by the Picture Drawing Program, require an understanding of the purpose and methods of handling the geometry storage tape (Tape Unit 8). The important features of this aspect are illustrated in Figure 8, by the flow chart on page C-17, and also by the outline below.

1. All input geometry data, regardless of form (i. e., ellipse, parametric cubic) must eventually be converted to surface-element form, so that the plane quadrilaterals can be constructed by the SDATA routine.

2. Surface-element data generated by the ellipse-generation option, by the parametric-cubic method, or by an auxiliary program such as the slab-delta-wing routine, are recorded on the geometry storage tape (Tape 8) in surface-element form.

3. Each of the program geometry options has an input flag that controls the position of Tape 8 after the option has written element data on it.

4. The position of Tape 8 at the start of each problem phase is also controllable by an input flag (Tape 8 may be left in its current position or be completely rewound).

5. Geometry data originally input in surface-element form from the standard input tape (Tape 5) may also be copied onto Tape 8.

6. As was mentioned previously, surface-element data must eventually be converted by the program into plane-quadrilateral data. In the process, the element data may be scaled or shifted relative to the original coordinate system by inputting scaling factors and scale-shift increments. An input flag (ITAPE) is provided to designate whether the element data to be converted to quadrilaterals will be read from the standard input tape (Tape 5) or from the geometry storage tape (Tape 8). If the element data are being read from Tape 8, the flag also determines whether the reading of data is to start with Tape 8 in its current position or if the tape is to be rewound to the beginning before reading starts. This option will be more understandable after a reading of the detailed description of the program input control flags and studying page C-17.

   As the user sets up his problem, he will find it helpful to keep a running chart indicating the position of Tape 8 for each part of the problem.

Verification of Geometry Data

Once the input geometry data are prepared, the user has a decision to make. If the geometry of the vehicle is very simple and the user has confidence that there are no errors in the data, he may elect to make an all-in-one machine pass. In this case the geometry data can be submitted with necessary AERO Program control data, and the program is run. But it is wise to first verify the accuracy of the geometry data by use of the Picture Drawing option. If the vehicle is described completely by surface-element data, these data may be submitted directly to the Picture Drawing Program option. However, in most cases the vehicle will be described by a combination of input surface-element data, ellipse-generation data, and parametric-cubic data. For this type of problem, the raw geometry data are submitted to the AERO part of the program, where they are converted into surface-element data (if required) and placed on the geometry storage tape (Tape 8). During this operation it is not necessary to have the program convert the element data into quadrilaterals, since a control flag will be used to bypass the force-calculation part of the AERO program (IRET1). After the geometry data have been assembled onto Tape 8 in surface-element form, system control is returned to the Executive Program. The Executive Program then passes control to the Picture Drawing Option, where the surface-element data on Tape 8 are read and pictures are produced.

Examination of pictures of the vehicle from several different viewing angles will permit the detection of all geometry errors. Errors in the original raw geometry data are then corrected before the data are resubmitted to the program for aerodynamic computations. On the final machine pass, pictures may again be produced to verify the correction and to serve as a final record of the geometry representation used in the aerodynamic analysis.

AERO PROGRAM CONTROL

The organization of the input data for the AERO program is discussed in detail in a later section of the manual. At this time we need only furnish a few guiding principles. The input data for the AERO program is "free form" in nature; that is, the order of input cards depends upon the problem being solved. The order in which the program expects to read input cards is controlled by special flags on previous input cards. The general features of the AERO program input data technique are shown on page C-17. A thorough study of this diagram will indicate a number of important AERO program control concepts. First, each component of a vehicle may be analyzed by the program as though it were a complete vehicle by itself. The resulting aerodynamic characteristics may be saved for subsequent summation, along with those of other components, to give the complete vehicle characteristics. This technique permits the user to perform a complete buildup of the vehicle characteristics, component by component. However, the user is cautioned that the program does not account for interference or mutual-interaction effects between components.

PRESSURE-CALCULATION METHODS

The pressure-calculation method is the most important single piece of data input to the AERO program. A complete discussion of this part of the problem solution is beyond the scope of this report. Such a discussion would involve a review and presentation of information available in numerous hypersonic textbooks and in hundreds of technical reports. Therefore, only a brief discussion of this problem will be included in this report (see Appendix A).

The aerodynamic literature contains descriptions of many different methods for calculating the pressures on hypersonic vehicles. Each method is tailored to a particular application, either by the geometry assumed or by the assumptions made in the gas-dynamics relationships. It is obvious that no one method will suffice for all shapes and flight conditions. Indeed, different methods must frequently be used for different components of a single vehicle. The logical approach in the development of this analysis system was to include a large number of different force-calculation methods. As new methods are devised and validated, they may be added to this system. The selection of the proper method in a given application depends upon the vehicle-component shape and flight condition and must be selected by the engineer on the basis of his knowledge and experience in the use of each method.

The Mark III Version of the Hypersonic Arbitrary Body Aerodynamic Computer Program System contains the following pressure-calculation methods. These methods, along with the pertinent references, are discussed in more detail in Appendix A.

1. Modified Newtonian. The modified Newtonian method is probably the most widely used of all the hypersonic force analysis techniques because of its simplicity and experimentally confirmed

accuracy for many hypersonic problems. In its purely empirical form, the modified Newtonian relationship is $C_p = K \sin^2\delta$ where K is an empirical correlation factor. In general, K is a function of Mach number, angle of attack, component shape, and gas composition. The use of relatively simple techniques such as modified Newtonian, when combined with empirical correlations and an arbitrary body-surface-description method, provides a powerful tool for analyzing many hypersonic shapes.

2. Modified Newtonian + Prandtl-Meyer. This method is useful for the nose regions of very blunt shapes. The flow model used assumes a blunt body with a detached shock, followed by an expansion around the body to supersonic conditions. As the name indicates, the method uses a combination of modified Newtonian and Prandtl-Meyer expansion theory. Modified Newtonian theory is used along the body until a point is reached where both the pressure and the pressure gradient match those that would be calculated by a continuing Prandtl-Meyer expansion.

3. Tangent Wedge. This method is frequently used to calculate the pressures on sharp two-dimensional bodies. This method has been suggested by the results of more nearly exact theories that show that the pressure on a relatively flat surface in impact flow is primarily a function of local surface slope. In this method, a plane surface is assumed to be tangent to the vehicle at the point being studied. The surface pressure is assumed to be the same as would exist on this tangent plane. The tangent-plane pressure is calculated with conventional oblique-shock relationships. This method will give useful results up to the shock-detachment condition.

4. Tangent-Wedge Empirical. This method is similar to the tangent-wedge method (oblique-shock tables) but is empirical in nature and does not require the use of the oblique-shock tables. The empirical relationship used will also give a smooth trend of pressure through the shock-detachment condition and on to the blunt stagnation condition. At high angles of attack the pressures obtained will approximate oblique-shock values calculated with an infinite Mach number.

5. Tangent Cone Empirical. The computation of exact cone properties would not be possible in a program of this size. Instead, tangent-cone results are obtained through the use of a simple empirical equation. The principle involved in the use of tangent-cone theory are similar to those used for tangent-wedge except that the method is usually used for curved shapes such as bodies of revolution and for very highly swept surfaces.

6. OSU Blunt Body Empirical. This empirical method may be used to determine the pressure distribution about cylinders in supersonic flow. It should not be used on the afterbody portions of a vehicle.

7. Van Dyke Unified Method. (Small disturbance.) This force-calculation method is based on the unified supersonic-hypersonic small-disturbance theory proposed by Van Dyke as applied to basic hypersonic-similarity results. The method is useful for thin profile shapes and, as the name implies, is applicable down to the supersonic speed region.

8. Blunt-Body Shear Force Method. This force calculation option is used to calculate the skin friction shear force contributions on very blunt shapes. Even though this is not really an inviscid pressure method it is included in this list because its use in the program is similar to the other inviscid pressure methods. Force contributions calculated by this method must be added to results obtained with the regular inviscid pressure calculation methods (usually modified Newtonian or modified Newtonian + Prandtl-Meyer). The method is applicable over a wide Reynolds number range although the results are more significant, in terms of effect on the total vehicle characteristics, at the lower Reynolds number flight conditions.

9. Shock-Expansion Method. (Strip-Theory.) This force-calculation method is based on classical shock-expansion theory. In this method, the surface elements are handled in a strip-theory manner. The characteristics of the first element of each longitudinal strip of elements may be calculated by oblique-shock theory, by conical-flow theory, by a delta-wing empirical method, or by a Prandtl-Meyer expansion. Downstream of the initial element, the forces are calculated either by a Prandtl-Meyer expansion or oblique-shock methods. By a proper selection of the element orientation, the method may be used both for winglike shapes and for more complex body shapes. For the latter, the method operates in a hypersonic-shock-expansion-theory mode. This method is used when it is necessary to account for the effects of surface corners (such as the extension from a forward lower-ramp to an aft flat surface on many typical high lift-to-drag-ratio reentry vehicles). The user should take special note that this method can be applied only within one single section of a vehicle. Also, the shock-expansion computations are performed in a stripwise mode where the flow direction is as defined by the input strip of surface elements. The first element in each streamwise strip of each vehicle section is defined as being the leading-edge element.

10. Free Molecular Flow. This method is used for flight at very high altitudes, where conventional continuum-flow theory fails and one must begin to consider the general macroscopic mass, force, and energy-transfer problem at the body surface. This condition occurs when the air is sufficiently rarefied so that the mean free path of the molecules is much greater than a characteristic body dimension.

11. Input Pressure Coefficient. In some situations the user may wish to impose a known pressure coefficient over a portion of the vehicle shape. This is most frequently used when accounting for base-pressure effects.

12. Hankey Flat-Surface Empirical. This method uses an empirical correlation for lower surface pressures on blunted flat plates. The method approximates tangent-wedge at low impact angles and approaches Newtonian at the high impact angles.

13. Delta-Wing Empirical Method. This method uses an empirical relationship derived from tunnel data on delta-wing surfaces. At low angles of attack, the results approximate tangent-wedge pressures; at high angles of attack, they approach cone and Newtonian results.

14. Dahlem-Buck Empirical Method. This method uses empirical relationships that approximate tangent-cone results at low impact angles and Newtonian at high impact angles.

15. Blast Wave Pressure Increments. This method uses conventional blast-wave relationships to calculate pressure increments due to bluntness effects. Force contributions calculated by this method must be added to the forces calculated using the regular tangent-surface pressure forces as calculated over the same surface geometry.

16. Modified Tangent-Cone. This method was originally developed for use on elliptical cones. The method modifies regular tangent-cone results by an increment representing the tangent-cone pressure deviation from the average surface pressure divided by the average surface Mach number.

17. Boundary Layer Induced Pressures. This method calculates the vehicle force increments caused by boundary layer displacement effects. These force increments should be added to the regular inviscid vehicle force characteristics. For this method the boundary layer induced pressures are calculated using the vehicle skin friction geometry model. The data deck set-up must be exactly like that used for the skin friction calculations. The boundary layer induced pressures are corrected for three-dimensional effects using the skin friction element planform information. If the tangent-cone method is used to calculate the local flow properties, a correction to the induced pressure calculations will also include the effect of this conical deviation from oblique shock results.

18. Prandtl-Meyer Expansion from Free Stream. In this method the flow is assumed to have expanded from free-stream conditions to the local surface slope. The method is useful for the shadow portions of the vehicle when the use of shock-expansion is not possible.

Before the program calculates the pressure on each surface element, it checks to see if the element is facing the flow (in an impact region) or facing away from the flow (in a shadow region). The method to be used in calculating the pressure in impact and shadow regions may be specified independently. A summary of the program pressure options is presented below.

PRESSURE CALCULATION METHODS – MARK III MOD 0 PROGRAM

Impact Flow

1. Modified Newtonian
2. Modified Newtonian + Prandtl-Meyer
3. Tangent-wedge
4. Tangent-wedge empirical
5. Tangent-cone
6. OSU blunt-body empirical
7. Van Dyke Unified
8. Blunt-body skin friction
9. Shock-expansion
10. Free-molecular flow
11. Input pressure coefficient
12. Hankey flat-surface empirical
13. Delta wing empirical
14. Dahlem-Buck empirical
15. Blast wave
16. Modified tangent-cone
17. Boundary layer induced pressures

Shadow Flow

1. Newtonian ($C_p = 0$)
2. Modified Newtonian + Prandtl-Meyer
3. Prandtl-Meyer from free-stream
4. OSU blunt body empirical
5. Van Dyke Unified
6. High-Mach base pressure ($C_p = -1/M^2$)
7. Shock-expansion
8. Input pressure coefficient
9. Free-molecular flow
10. Boundary layer induced pressures

The user should note that the program handles each element separately, as though it were the entire vehicle (with the exception of the shock-expansion methods). The program does not have any way of determining if some other portion of the vehicle blocks the flow from the element. This type of situation must be handled by a proper selection of geometry description methods and by careful deletion of those portions of the geometry that would be subjected to shielding. The user may easily determine what portions of the vehicle would be shielded by other parts at different angles of attack by having the Picture Drawing Program draw pictures of the vehicle at the desired flight condition.

In all methods except the shock-expansion and the Newtonian + Prandtl-Meyer, the pressure depends only on the angle that the local surface makes with the free-stream flow. All these local slope-dependent methods are particularly applicable to the hypersonic arbitrary-body problem, since the interaction of different vehicle elements is assumed to be negligible. Fortunately, this is true of many hypersonic problems.

VISCOUS FORCES

The most difficult part of the analysis of arbitrary shapes is the calculation of viscous forces. The natural complexity of the boundary-layer equations requires considerable simplification before solutions can be obtained. The analysis of the arbitrary-body boundary layer is hampered by two basic problems: (1) the boundary-layer properties at a given point on the vehicle require knowledge of the previous flow history along surface streamlines, and (2) as a result of longitudinal and transverse surface curvature, complex surface gradients are present. It is sufficient to state that a unified theory that deals with the three-dimensional boundary layer does not exist.

Notwithstanding the difficulties of this problem, an approach has been selected that retains the essential characteristics of the hypersonic-boundary-layer problem and gives sufficient accuracy for most purposes. In this approach, no attempt is made to calculate the detailed skin friction over the exact surface of the arbitrary shape used for the pressure calculations. Instead, a separate geometry model is used that contains a fewer number of elements (usually 10 to 20 elements), yet still approximates the major features of the vehicle. The regular surface element input method is used in preparing this geometry data. A comparison of the geometry data usually prepared for the pressure calculations and the skin friction geometry model is presented in Figure 15.

Each element of the skin friction geometry model is treated as a separate skin friction surface. The orientation and position of each skin friction surface element is determined using the same procedures as for the inviscid pressure calculations. However, in addition to these data, additional information is needed before the skin friction calculations can be made. This information includes data that defines the boundary layer flow history in reaching each element, and that indicates the planform shape of the element over which the shear forces are to be integrated. This is accomplished by the use of an initial surface in front of each skin friction element. This information, together with several skin-friction option selection flags, is input on skin friction data cards.

The skin friction calculations also require knowledge of the local flow properties (pressure, Mach number, and temperature) on each skin-friction element. These data are calculated using several of the methods provided for use in the detailed inviscid-pressure calculations. The options provided for this purpose are tangent-wedge, tangent-cone, delta-wing empirical, Prandtl-Meyer expansion from free-stream, and blunt body Newtonian-Prandtl-Meyer.

The free-stream-flow properties required in the skin friction calculations may be determined either from the U.S. 1962 Standard Atmosphere routine provided in the program or by using input wind-tunnel conditions of stagnation pressure and temperature. The latter calculations use ideal-gas isentropic relationships for air. To match the stream flow conditions for some high-temperature hypersonic test facilities, the user will have to make some adjustments in input stagnation pressure and temperature to account for real-gas effects.

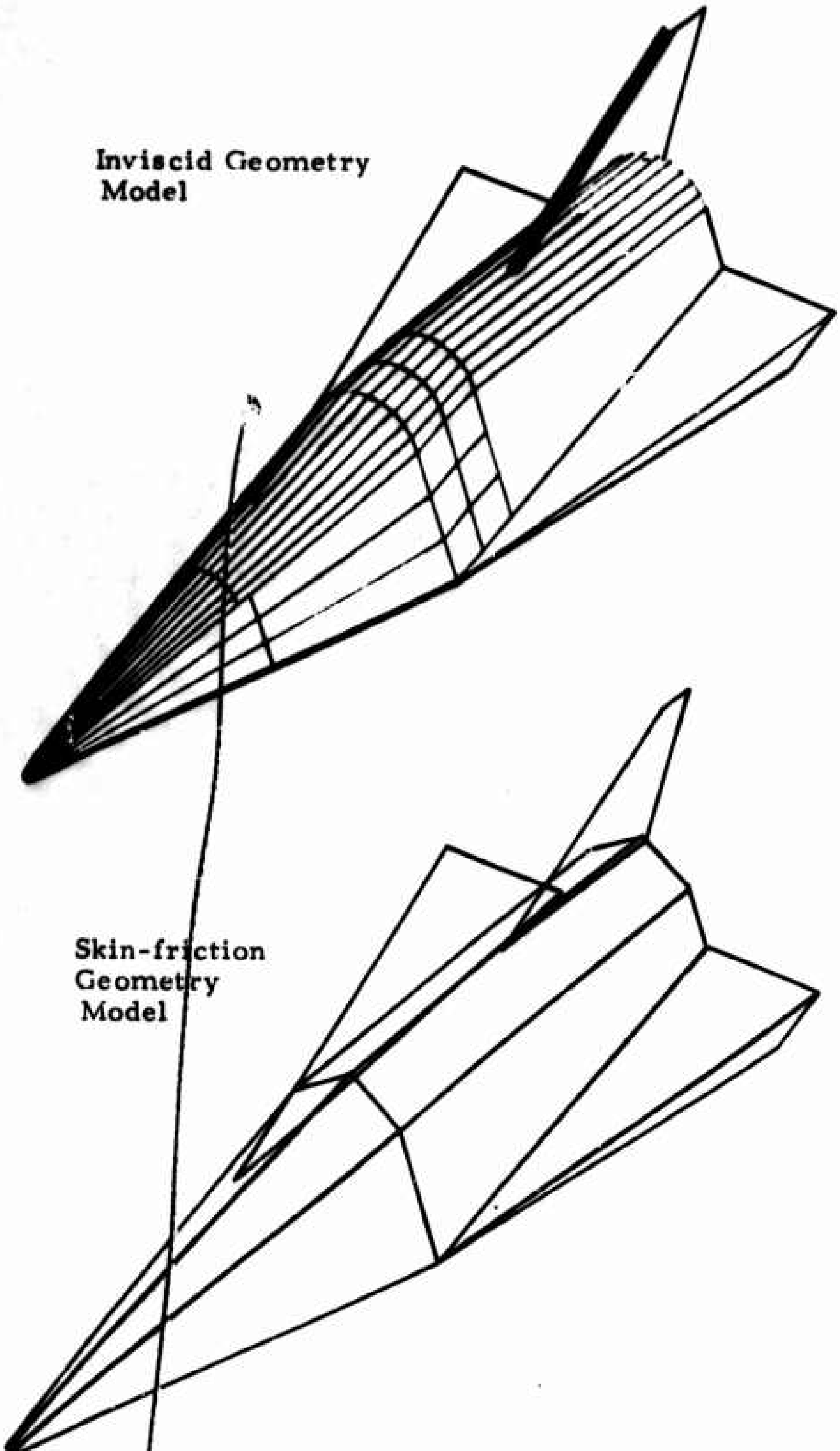


Figure 15. Comparison of Inviscid Geometry Model with Skin-friction Geometry Model

After the local flow properties on the skin friction element have been determined the program will proceed with the calculation of the element wall temperature and the resulting skin friction forces. The options provided in the program for these calculations are the reference temperature and reference enthalpy methods (for both laminar and turbulent flows), and the Spalding-Chi method for turbulent calculations (using either temperature or enthalpy ratios). The surface temperature is either input to the program or the radiation equilibrium value determined using the selected option.

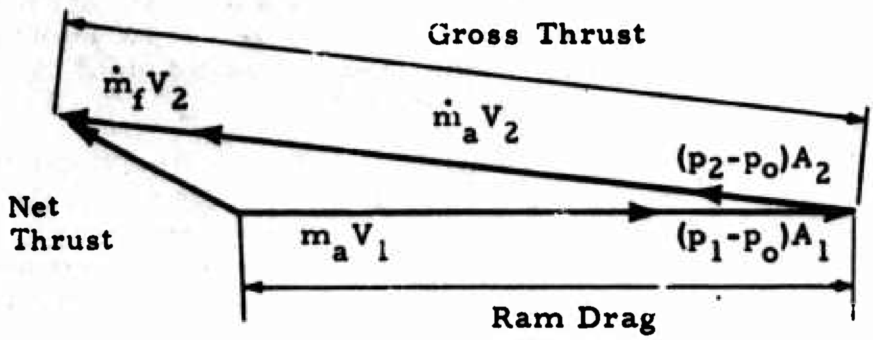
The user should note that the skin friction geometry model is provided for the primary purpose of establishing the orientation and position of the desired skin friction surface elements (element centroid and surface normal). The wetted area of each skin friction element may be either input on the skin friction data card or calculated from the geometry model (if skin friction data card area is input as 0.0). These options are provided because the desired element wetted area may differ from the skin friction geometry model area due to the deletion of local surface curvatures. The exact surface areas for each part of the vehicle may be obtained either from the printed output from the Picture Drawing Program or from the AERO program. This of course requires a preliminary program run with the corrected geometry data. The vehicle aerodynamic characteristics need not be calculated on this machine pass unless the user wants to obtain inviscid-characteristic results.

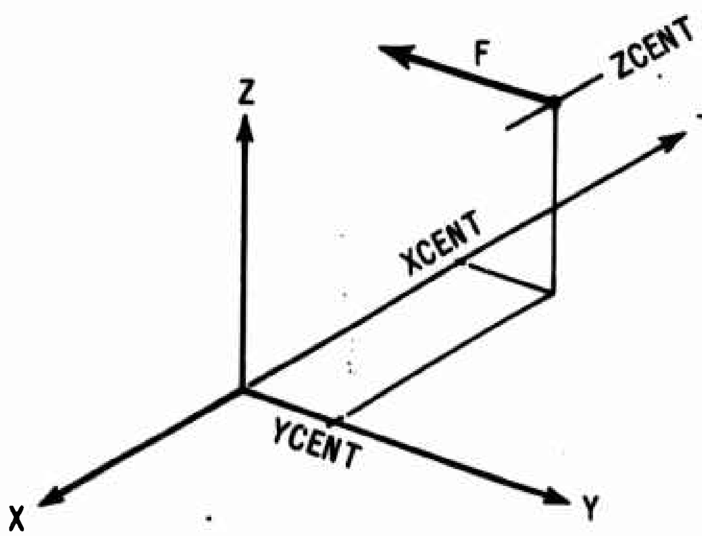
The skin friction calculations include the effects of viscous-inviscid interactions on the shear forces. The contribution of these effects to vehicle pressure forces may be obtained with the use of the boundary-layer induced pressure option provided in the normal inviscid pressure part of the program. The deck set-up for these calculations is exactly like that required for the skin friction calculations (complete with skin friction geometry model and skin friction data cards) except for the specification of the pressure calculation method options.

The above discussions have been primarily concerned with skin friction calculations on slender configurations. However, blunt shapes such as the early space capsules may also be strongly influenced by viscous effects at some flight conditions. A separate skin friction option is provided within the program for this type of application. Because the analysis methods used are only local-slope dependent these calculations may be performed over the surface of the detailed inviscid-geometry model rather than using a separate and simplified skin friction geometry model. The blunt body viscous option is, therefore, used in a manner similar to the other inviscid force calculation options. The viscous force increments obtained must then be added to the regular inviscid pressure force contributions using the program component-summation techniques.

PROPULSION EFFECTS

The design and operation of an air-breathing propulsion system of a hypersonic vehicle can have a strong influence on vehicle stability and control characteristics. For some aircraft, such as scramjet-powered vehicles, the engine, including the inlet and exhaust system, may be highly integrated into the vehicle design. For these configurations, the bookkeeping system as to what is engine and what is airplane is no longer easy to resolve. A detailed analysis of this type of problem is obviously beyond the scope of this computer program system. The program does, however, have the capability of properly using the results from more detailed propulsion studies in evaluating the total-vehicle stability characteristics. If the user wishes, he may input to a program several force vectors that represent the major component forces created by the engine system. The vector relationships for a simple engine system are illustrated in the diagram below. Also shown is the coordinate system used in preparing the force vector data for use by the program.





NX, NY, NZ are direction cosines of F

The input data to the program include the magnitude of each force, its direction, and its point of application on the vehicle relative to the center of gravity. The use of the input thrust-vector part of the program should be restricted to basic-vehicle-coefficient computations. Thrust-vector effects on vehicle stability derivatives are not obtained directly by the program. However, these effects on the stability derivatives may be obtained by calculating vehicle static coefficients at two different angles of attack and computing the derivatives by hand.

CONTROL-SURFACE EFFECTS

Several comments should be made relative to the program computation of control-surface effects. First, the program is capable of analyzing a vehicle with any number of control surfaces, and the various surfaces may be deflected in different directions. The program is also capable of calculating control-surface derivatives and surface hinge moments. Because of this very general and flexible approach to the control-surface problem, the user will have to apply special care in the interpretation of the output data and in the sign convention used for control-surface deflections.

The boundary layer flow-separation phenomenon is an important feature of the flow about a hypersonic control surface. Flow separation on the control surface and on the surface of the vehicle ahead of the control can have a pronounced influence on control effectiveness. This is a very difficult problem to analyze theoretically. However, the use of a simplified flow model and empirical boundary-layer-separation data allows the solution of this problem with sufficient accuracy for most preliminary design purposes.

To properly account for these flow-separation effects, it has been necessary to establish certain fixed procedures to be used in representing a control-surface geometry for the program. These procedures are discussed below.

Each vehicle control surface must be analyzed as a separate vehicle component. The geometry of the control surface is input to the program in the undeflected position. The program will take care of deflecting this surface to the proper position as required. The hinge line of each control surface must be a straight line. For many hypersonic flight conditions, the deflection of a control surface will cause flow separation on the vehicle surface ahead of the flap. To permit the proper analysis of this effect, the user must input the surface of the vehicle that may be influenced and at the same time input the control-surface geometry. The vehicle surface just ahead of the flap is called the flap "fore-surface." Since the program will use shock-expansion techniques to analyze the separation effects, it is necessary that the fore-surface and the flap have the same number of streamwise strips of elements. It is also necessary that each strip contain a sufficiently large number of elements so that the flow-separation pressures can be properly distributed along the vehicle.

In the Mark III version of the System, the fore-surface and control-flap-geometry data are stored on magnetic tapes. Because of this, machine computation times for control surfaces are relatively high.

The input fore-surface and flap-geometry element data must be arranged in a stripwise order (IORIEN ≥ 1).

In the preparation of control-surface geometry data, each side of the control surface is handled as a separate vehicle component. And, regardless of the orientation of the fore-surface and control flap, a positive control-surface deflection always means that the flap is deflected outward into the flow. This may cause some users difficulty in analyzing the program results, but it is necessary to maintain the complete generality desired within the program. A negative surface hinge moment represents forces tending to return the surface to the undeflected position.

A control surface may be oriented in any position desired. The surface hinge line, however, must be a straight line.

The flow separation criterion used in the program is based on the analysis of test data where both the fore-surface and flap were flat surfaces. Although this requirement is not imposed in this program (curved arbitrary shapes for both the fore-surface and flap may be used), the user should realize that he is deviating from the verified bounds of the empirical separation equations used.

The Mark III version of the program is also capable of handling all-movable control surfaces (flying tails). This is accomplished as follows. First, the IGTYPE flag must be set =3 for this component of the vehicle. This component must consist of two sections just as was discussed above for a conventional flap-type of control surface (a fore-surface followed by the movable surface). The fore-surface, however, is not actually a surface of the vehicle but is a very thin row of elements (with very small area) that represents the line about which the control surface is to rotate (the pivot line). This pivot-line row of elements should have a very small surface area so that the forces calculated on it do not significantly contribute to the over-all vehicle forces. Separation effects will not be calculated on this type of control surface.

SECTION III

INPUT DATA INSTRUCTIONS

GENERAL INFORMATION

The input to this program consists of several different types of data - System control data, AERO program control data, geometry data, Picture Drawing Program data, and Output Plotter Control data. Many different options are provided within this program. Although these options will be given in the input instructions that follow, their true significance and usage will probably be understood only after the review of a number of examples.

The organization of the input data for this program and the format of the input data cards are discussed on the following pages. Since the input cards are read into the computer by several different READ statements within a program, it is imperative that all the cards be in the proper sequence. To prevent the program from using erroneous data because of an error in card sequence, each different type of input data is identified by a card "TYPE" number punched in card columns 71 and 72. If the program detects an error in card type number, caused by a missing card, a card or cards out of order, or a card having an improper Type number, that phase of the program will be halted and control returned to the Executive Program. The last card in each phase option must contain the Type Number 99. If an input error is detected during the reading of cards for a particular phase, control will be transferred back to the Executive Program. The executor will then flush all of the data cards until it finds a Type 99 card. The program will then try to execute the next phase option. Of course, if the next phase option is dependent upon data generated in the previous phase, then it too may also have difficulty and result in a phase termination.

A number of different data input sheets are used with this program. These are listed below.

Sheet

1. System Control Data – Card Type 0.
2. Aerodynamic Program Control Data – Card Types 1, 2, 8, 9, and 10.
3. Element Data – Card Type 3
4. Ellipse Generation Data – Card Types 4 and 5.
5. Parametric Cubic Patch Data – Card Types 6 and 7.
6. Skin Friction Data – Card Type 11.
7. Flight Attitude Data – Card Type 12.

Sheet

8. Coefficient Increment Data – Card Type 13.

9. Plunge Derivative Data – Card Types 14 through 21.

10. Thrust Vector Data – Card Type 22.

11. Picture Drawing Program Data – Card Types 31, 32, 34, 35, 36, and 37.

12. Plotter Program Control Data – Card Types 41, 44, 45, 46, 47, and 48.

13. Slab Delta Geometry Data – Card Types 50, 51, and 54.

The required order of cards varies, depending upon the type of problem being run. The various control flags on the input data sheets inform the program of the type of card and data to be read next.

Before going into a discussion on each of the input items, it will be helpful to review briefly the basic philosophy involved in setting up a machine run. The input data sheets used for this program are shown on pages C-3 through C-15. These pages may be folded out for reference. Careful study of the following discussion on the most important control parameters on these input sheets will make subsequent descriptions of each input parameter more meaningful. Input data flow charts are shown on pages C-17 through C-25.

The basic control of the reading of input data and the operation of the program is directed by a few input flags. It is vital that the user understand the operation and the use of these key input items, since they provide the program with its great flexibility.

In general, the key input control flags are located in card columns 60 through 65. The most critical flags on the input sheet are outlined with a heavy border.

EXECUTIVE CONTROL DATA

The Hypersonic Arbitrary Body Aerodynamic Computer Program System is controlled by a single System Control Card (Sheet 1). This card controls the selection of each program option and the order in which options are to be used. the Mark III version of the program has five phase options available.

Option 1. Aerodynamic Program

Option 2. Picture Drawing Program

Option 3. Output Data Plotter Program

Option 4. Slab Delta Geometry Generation Program

Option 5. Geometry Card Punch Program

Up to twenty different program phases may be used, and any given option may be used several times. The system control card must contain a zero in card column 72. A card sequence number may be placed in card columns 77 through 80, to help keep the cards in order. This number must be a right-justified integer.

AERO PROGRAM

Before presenting detailed descriptions of the Aerodynamic Program input data, eachof the key control flags will be discussed briefly. The reader should refer frequently to the appropriate fold-out input data sheet on pages C-3 through C-15 and the flow charts on pages C-17 and C-25.

The parameter ISUM in card column 60 of the Type 1 Element Data Control Card is the vehicle-component-summation control flag. This flag controls the recording of force data for each component of the vehicle and tells the program when to sum up the component data. If the program is told to sum a set of force data, then after this is accomplished the program will return to read another element data title card (for the next component). This control flag also controls the position of the data summation tape. The Aerodynamic Program always starts and ends with the reading of an element data title card. If this card contains a Type number of 99 then control will be returned to the Executive Program. The parameter IREW8 in card column 61 is used to rewind the geometry storage tape (Tape 8).

The next card in the deck will usually be the Element Data Control Card (Type 2 card). The key control flags on this card are the parameters IGEOM, ITAPE, IGTYPE, and IELOV (card columns 60 through 63). The geometry source flag, IGEOM, informs the program of the source of the geometry data—either input surface element data, ellipse generation data, or parametric cubic data.

The geometry tape flag, ITAPE, indicates the tape to be read to obtain the geometry <u>element</u> data (either regular input Tape 5 or special geometry storage Tape 8), and can also direct the storage of this data on the special geometry storage tape. All element geometry data generated by the ellipse generation routine or by the parametric cubic input method is stored on the geometry storage tape in element data form. After a machine run this tape may be saved and BCD cards punched from it to give regular surface element data that may be used on subsequent runs. The geometry data on Tape 8 may also be read directly by the Picture Drawing Program. Figure 8 on page 20 illustrates the basic concepts involved in the use of the geometry storage tape.

The two control flags IGEOM and ITAPE must be clearly understood by the user. These flags control a two-step operation. First, the IGEOM flag indicates merely the type of geometry data to be expected (either element data, ellipse generation data, or parametric cubic boundary data). The control flag, ITAPE, is completely independent of the geometry source flag and is used to inform the program as to where it is to obtain the surface element data in order to perform the quadrilateral element calculations (see page C-17).

The parameter IGTYPE indicates the type of geometry data input to the program (regular geometry data for pressure calculations, control surface geometry data, or skin-friction geometry data).

The element characteristics override flag, IELOV, on the Element Control Data Card is used to bypass the conversion of element geometry data into the quadrilateral data required for force calculations. This option is used when it is desired to generate and assemble the geometry data in regular element form without actually calculating vehicle forces. This technique is useful when assembling and checking out a geometry deck where the Picture Drawing Program is to be used next.

If geometry data cards are to be input to the program, they must follow directly after the Type 2 element data control cards. If the geometry data are to be read from Tape 8, these cards will not be present.

After the geometry data cards the program will expect to read the Force Data Title card (Type 8). If this card contains a 1 in card column 60, the program will next return to read another Element Data Title Card (Type 1). This will allow the program to bypass any force calculations. If the Force Data Title Card contains a 0 in card column 60, the program will proceed to read a Flight Condition Card (Type 9) and then the Center-of-Gravity Data Card (Type 10).

The key control parameters on the Flight Condition Card are the "last flight condition" flag (card column 60), the "number of angle-of-attack and sideslip-angle combinations" flag (card column 61-62), the "use old alpha-beta" flag in card column 63, and the "number of skin friction surface" flag (card column 64-65). These flags control the exit from the force calculation to a new set of geometry data, the number of flight-attitude data cards to be read (if the "no alpha beta cards" flag has been set to 1 then no Flight Attitude Cards will be read), and the number of skin friction cards to be expected.

Complete mastery of all the above key control flags is required for successful operation of the AERO program. This can be achieved by a strict adherence to the detail input instructions for each of these flags, by studying the sample problems provided, and by a careful checking of the input data cards before making a run. In making this check of the input data the user will find it helpful to have a machine listing of all the data cards.

Detailed information of the data to be given on each type of input card is given by the following discussions. All input data are real numbers except as noted in these instructions. Real numbers are written with the sign (if negative) and the decimal point (i.e., -14.952). Real numbers may be written anywhere in the field required but are usually placed to the left side of the field. Integer input numbers are written without the decimal point and must be placed at the right side of the field provided (right-justified).

Because of the free-form nature of the program input data it will be necessary to rearrange the cards after they have been punched from the various input sheets. This may be facilitated by the use of the sequence numbers in card columns 77-80.

AERODYNAMIC PROGRAM CONTROL DATA

Element Data Title Card - This card contains the element data title and the component summation flag. See sheet 2, page C-3.

Card Type	Column	Code	Explanation
1	1-59	TITLE	The title that is to appear at the top of the element data output pages. Any acceptable machine characters.
	60	ISUM	Component save and summation flag. A special flag to control the saving of force data from component to component and to control the summation of data and the position of the component summation tape after summation. (Integer)

= 0 If force data for this run are not to be summed or saved for future summation.

= 1 If the force data for this vehicle component are to be saved for subsequent summation with other components.

= 2 Previously saved force data are to be summed and printed out. After the summation data are printed, the program then returns to read another Element Data Title card. The summation data tape is not rewound but left standing ready for the next set of saved data.

= 3 Sum all data on summation tape and print out. Summation tape will be rewound before reading the next set of data. An Element Data Title card will be expected next.

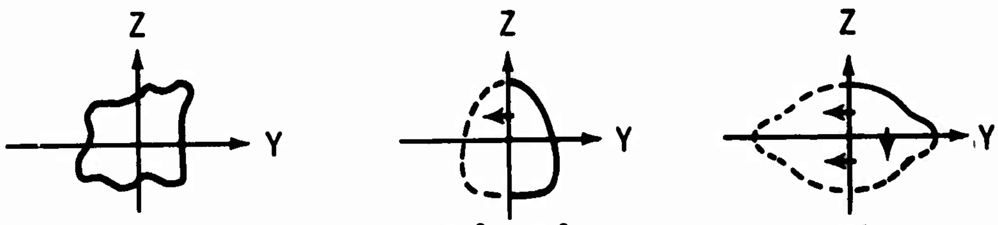
= 4 Sum all data on summation tape and print out. The summation tape will be backspaced one set of summation data for reading in the next set of data. This will, in effect, delete the last set of saved data so that it can be replaced by future saved data. An Element Data Title card will be expected next.

= 5 Sum all data on summation tape and print out. The summation tape will be rewound and the results of the summation written at the beginning of the tape for addition with subsequently saved data. The tape will be left in a position for the second set of summation data. An Element Data Title card will be expected next.

Card Type	Column	Code	Explanation
1	61	IREW8	This flag controls the position of the geometry storage Tape 8. (Integer) = 0 Do not rewind Tape 8 but start problem with it in the current position. = 1 Rewind Tape 8 before reading Element Data control card.
	63	IPS	SC-4020 plotting tape control flag for summation data. (Integer) = 0 Summation force data are not to be placed on the SC-4020 plotting tapes (Tapes 9 and 10). = 1 Summation force data are written on the SC-4020 plotting tape.
	64	IABDOT	This flag is used to indicate when plunge derivatives $C_{m_{\dot{\alpha}}}$ and $C_{Y_{\dot{\beta}}}$ are to be calculated using summation data characteristics. (Integer) = 0 Plunge derivatives will not be calculated. = 1 Plunge derivatives will be calculated using the summation data $C_{m_{\alpha}}$ and $C_{Y_{\beta}}$. The next card must be the plunge derivative control card (Type 14).
	65	IVECT	This flag is used to indicate when the program is to read thrust-vector data for inclusion with the summation data. (Integer) = 0 Thrust-vector data are not used. = 1 Thrust-vector data will be calculated and added to the summation data. The next card must be a thrust vector, Type 22 card.
	66-68	CASE	Case number to be printed out at the top of element data output (right-justified integer).
	72	TYPE	Card Type number = 1 (integer)
	77-80	SEQ	Sequence number for use in keeping cards in proper order. This number is not read by the program (right-justified integer).

Element Data Control Card - This card controls the reading in of surface element data.

Card Type	Column	Code	Explanation
2	1	PRINTS	Flag to control the printing of detailed characteristics of each quadrilateral element. Data printed include · location of four corner points, centroid of area, direction cosines, and area of each element. This generates a large amount of output and increases machine time. (Integer) = 0 Do not print element characteristics. = 1 Print element characteristics.
	3	SYMFCT	Symmetry flag. This flag indicates the type of vehicle symmetry to be used for this component of the vehicle (see diagrams below). (Integer)

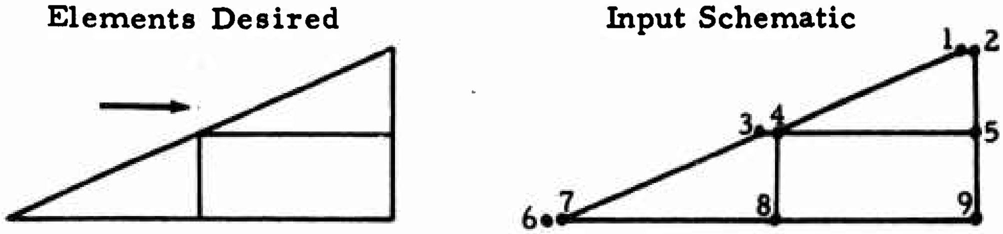


= 1   = 0 or = 2   = 3

Note: Although it is possible to use different Symmetry flags for different components of a vehicle, the safe thing to do is to input or generate the geometry using the same Symmetry flag for all components. This is particularly important if pictures are to be drawn by the Picture Program.

Card Type	Column	Code	Explanation
	4	IORIEN	Element orientation. (Integer) = 0 Normal mode using cross-sections. = 1 Geometry data input in streamwise strips. = 2 Geometry data input in streamwise strips. For each streamwise strip of elements the first coordinate point in the right-hand strip of points is not used in the formation of the leading edge element but is ignored by the program. This is illustrated in the diagrams below for the lower surface of a vehicle. The streamwise direction is indicated by the arrow. (continued)

Elements Desired   Input Schematic

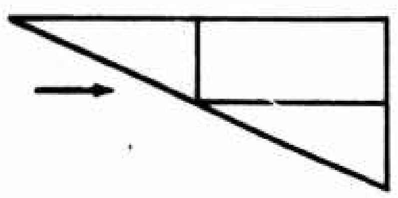


4 IORIEN (Continued)

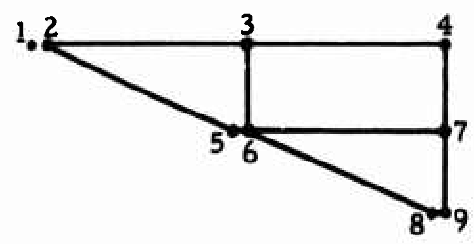
In the Input Schematic at the bottom of the previous page the numbers indicate the order of the input points. Note that points 1 and 2 are duplicate points (same values for X, Y, and Z) as are points 3-4, and 6-7. The first element is formed by input points 1-2-4-5 and point 3 is not used for this leading edge element. In a similar manner, an element is formed by points 3-4-7-8 and point 6 is not used.

= 3 Same as =2 above except that the left point is ignored in the formation of the leading edge elements. This would be useful for upper surface of a delta wing. The input schematic for this case is shown below.

Elements Desired



Input Schematic



5 IFACT Scale factor flag. This flag permits the alteration of geometry data for the force calculations. (Integer)

= 0 Use input geometry coordinates (no scale factors will be used).

= 1 Use scale factors to scale and shift the geometry data in the basic coordinate system. Scale factors and coordinate increments are applied as the geometry data are being converted into quadrilateral data. The original data on Tape 5 or Tape 8 are not altered.

i.e. $X_{new} = X_{input} \cdot (XSC) + DELX$

etc. for Y and Z

7-12 XSC X Scale Factor (to be multiplied times X_{input})

13-18 YSC Y Scale Factor (to be multiplied times Y_{input})

Card Type	Column	Code	Explanation
2	19-24	ZSC	Z Scale Factor (to be multiplied times Z_{input})
	26-31	DELX	ΔX Scale - Increment to be added to X
	32-37	DELY	ΔY Scale - Increment to be added to Y
	38-43	DELZ	ΔZ Scale - Increment to be added to Z
	45-49	LEFCT	Leading-edge factor. This number is used with control-surface data. It is used in conjunction with XLEO to define the boundary-layer running lengths for the control-surface flow-separation calculations (real number). (See page 99.)
	50-56	XLEO	Leading-edge X increment. This number is used with control-surface data. It is used in conjunction with LEFCT to define the boundary-layer running lengths for the control surface flow separation calculations (real number). (See page 99.)
	60	IGEOM	Geometry Source Flag. This flag identifies the type of geometry data to be input for this component. (Integer) = 0 Surface element data = 1 Elliptical Shape generation data. = 2 Parametric Cubic boundary curve data. = 3 (not used at present time)
	61	ITAPE	Geometry tape control flag — This flag identifies the tape to be used in obtaining surface-element geometry data for subsequent program calculations. (Integer) = 0 Element data are to be read from standard input Tape 5 (normal mode). = 1 First rewind Tape 8 (geometry storage tape) and then read element data from it. = 2 Read element data from Tape 8 (do not rewind tape before reading this set of data). = 3 First rewind Tape 8, then read element data from Tape 5 (regular input tape) and write the data on Tape 8. = 4 Do not rewind Tape 8; read Tape 5 and write the element data on Tape 8. = 5 Do not read surface-element data (Tape 8 will not be read). Quadrilaterals will not be calculated. Program next expects to read a Force-Data Title card with a 1 in CC 60.

Card Type	Column	Code	Explanation
2	62	IGTYPE	Flag to indicate component type. (Integer)

= 0 This component is to be used for pressure calculations and is not a control surface.

= 1 This component is a control-surface component. The geometry cards that will be read next must include a fore-surface and a flap in that order. The first point of the fore-surface must have a STATUS flag of 2 as must the first point on the flap. The last point on the flap must have a STATUS flag of 3. Dummy (zero area) elements are not permitted on this component. A dummy element to give a STATUS = 3 flag cannot be used on this component.

= 2 Skin-Friction Surface. Each element in this component is to be considered as a separate skin-friction surface. This component can have only 10 elements (10 skin-friction surfaces). If more then 10 surfaces are required then another component must be used and the summation option used to add up the results of the aerodynamic calculations. Inviscid pressure forces will not be calculated by the program for this component. Note: This option is also used for the Induced Pressure calculation option (IMPACT=17).

= 3 All-Movable Control Surface. This vehicle component will be considered as being an all-movable control surface. The component must consist of two sections. The first section input must be a row of elements (with very small area) representing the line about which the surface is to rotate (the pivot line). This pivot line data must follow all the rules associated with the input of a regular control fore-surface except that there is only one element in each streamwise fore-surface strip. See page 50 for a more detailed description.

63	IELOV	Element characteristic override flag (integer). = 0 Quadrilaterals are to be calculated for use in force calculations. = 1 Do not calculate quadrilaterals, since force calculations are not to be made. As long as ITAPE is not equal to 5, the geometry data will continue to be read but the quadrilateral calculations themselves will be bypassed. The surface wetted areas printed will be = 0.0. The Type 8 force data Title card must contain a 1 in CC 60.
66-68	CASE	Case number not used by program (right-justified integer).
72	TYPE	Card type number = 2 (integer).
77-80	SEQ	Sequence number used to keep the cards in proper order (not used by the program).

Force Data Title Card - **This card contains the force-data title and a special flag to permit return to the Type 1 Element Data Title card.**

Card Type	Column	Code	Explanation
8	1-59	TITLE	Contains the title that is to appear at the top of the force data output pages. Any acceptable machine characters.
	60	IRET1	Flag to permit return to Type 1 card. (Integer) = 0 Program will expect a flight condition card next and will proceed with force calculations. = 1 Program will expect an Element Data Title card next. This flag is used when element data are read (and printed out if required) but no force calculations are to be made. This is sometimes useful when making preliminary checks of geometry data or when geometric data are being systematically built up and stored on Tape 8, but force calculations are not being made.
	66-68	CASE	Case number - not used by the program (right-justified integer).
	72	TYPE	Type number = 8 (integer)
	77-80	SEQ	Card Sequence number - not used by the program.

Flight Condition Card - This card contains flight condition data and flags to control subsequent flow in the program (see sheet 2, page C-3).

Card Type	Column	Code	Explanation
9	1-10	MACH	Mach number
	11-20	ALT	Flight altitude - feet
	21-30	SREF	Reference area for force coefficients (wing area). Must be in units consistent with input geometry data.
	32-36	PSTAG	Wind-tunnel stagnation pressure (atmospheres). =0.0 If U. S. 1962 Atmospheric properties are to be used at the input altitude. ≠0.0 Input altitude will be ignored and the input stagnation pressure and temperature will be used to calculate tunnel free-stream properties (using isentropic ideal-gas relationships).
	37-43	TSTAG	Wind-tunnel stagnation temperature, ^{o}F. This number will be used with the above pressure to calculate the tunnel free-stream properties.
	45	IPS	SC-4020 Force Data Plotting flag. This flag controls the placement of force data on a special tape to be used by the Output Data Plotter Program. (Integer) = 0 Do not put force data on the plotter tape. = 1 Write the force data for this component on the plotting tape for use by the plotter program.
	48	ITYP13	Flag for reading of Type 13 cards (not used very often) (integer). = 0 No Type 13 cards will be read. = 1 Type 13 cards will be read. A Type 13 card should be placed after each Type 12 card. The Type 13 cards will contain input values of the six aerodynamic force coefficients that will be added to the program-calculated coefficients. The Type 13 data will be in six fields of ten card columns each and the number 13 in CC 71, 72. The data are input in the following order: C_A, C_N, C_Y, C_ℓ, C_m, C_n. Stability-derivative contributions are not accounted for (see input sheet 8, page C-9).

Card Type	Column	Code	Explanation
9	53	IABDOT	This flag is used to indicate when plunge derivatives, $C_{m_{\dot{\alpha}}}$ and $C_{Y_{\dot{\beta}}}$, are to be calculated for this vehicle component. (Integer) = 0 Do not calculate plunge derivatives. = 1 Calculate plunge derivatives, using the $C_{m_{\alpha}}$ and $C_{Y_{\beta}}$ for this component. The program will expect to read a Type 14 plunge derivative control data card right after all the Type 12 cards.
	54	IVECT	This flag is used to indicate when the program is to read input thrust-vector data for summation with the vehicle-component force characteristics. (Integer) = 0 Thrust-vector data will not be read. = 1 Read force-vector data. Program will expect to read a thrust-vector card (Type 22 card) after all the Type 12 cards.
	60	LAST	Last Flight Condition flag. This flag controls the flow of the program after data are calculated for all angles of attack for this case. (Integer) = 0 After force data are calculated for all angle-of-attack and sideslip-angle combinations, the program will return to read a new Element Data Title card (Type 1). = 1 After the force data are calculated for all angle-of-attack and sideslip-angle combinations, return to read a new Force Data Title card to start a new flight condition cycle.
	61-62	NAB	Number of angle-of-attack or sideslip-angle combinations to be calculated. The program will try to read this number of Flight-Attitude Data cards (Type 12 cards). This number of Type 12 cards must be present unless the flag in CC 63 has been set = 1. NAB cannot be greater than 20. If NAB=0 and NOAB=1 then the program will use the last input value for NAB.

Card Type	Column	Code	Explanation
9	63	NOAB	No alpha-beta card flag. This flag controls the reading of the Flight-Attitude Data (Type 12) cards. = 0 Program will expect to read the number of Type 12 cards as indicated. = 1 Program will use the previous set of Flight-Attitude Data cards (Type 12 cards) and will not expect to read new Type 12 cards. Type 12 cards should not follow the Type 10 center-of-gravity card (integer).
	64-65	NS	Number of skin friction surface cards to be read in (maximum number of 10). This number of skin-friction surface cards (Type 11) must be present and located just behind the Type 10 center-of-gravity card. When IGTYPE = 2 on the Type 2 card then NS must equal the number of elements for this component. (right-justified integer).
	66-68	CASE	Case number – not used by the program (right-justified integer).
	72	TYPE	Card Type number = 9 (integer).
	77-78	SEQ	Sequence number – not used by the program.

Center of Gravity Data Card - This card contains center-of-gravity information and the vehicle characteristic lengths to be used in the moment calculations. This card must always follow the Type 9 card.

Card Type	Column	Code	Explanation
10	1-10	XCG	Longitudinal position of center of gravity for moment calculations. Note that X_{cg} will frequently be input as a negative number since the negative X-axis is usually taken as directed from the nose of the vehicle toward the tail.
	11-20	YCG	Lateral position of the center of gravity. Usually = 0.0.
	21-30	ZCG	Vertical position of the center of gravity.
	31-40	SPAN	Reference length to be used in rolling- and yawing-moment-calculations.
	41-50	MAC	Reference length to be used in pitching moment calculations.
	66-68	CASE	Case number – not used by the program (integer).
	71-72	TYPE	Card Type number = 10 (integer).
	77-80	SEQ	Sequence number – not used by the program (integer).

Skin Friction Data Card - This card contains the input data and flags for the skin-friction calculations. Two basic modes of operation are available. The first uses a special skin-friction geometry description (IGTYPE = 2 on the Type 2 card) to provide surface orientation data for the viscous calculations. The number of Type 11 skin-friction cards must be equal to the number of elements in the skin-friction geometry data. The number of skin-friction surfaces must also be input in CC 64-65 of the Type 9 Flight-Condition card. A maximum of 10 surface elements (10 Type 11 cards) may be used to approximate the vehicle shape for the skin-friction calculations. If more than 10 surfaces are required for an accurate shape description the vehicle skin-friction geometry data must be divided into several components with a maximum of 10 elements in each component. The data summation flag on the Type 1 card will be used to add up the skin-friction components to get the total skin-friction contribution to the vehicle forces. The second mode of skin-friction operation does not use input element data to give the surface orientation in space but instead obtains this information from the Type 11 card. The above two modes of operation will be referred to in the input instructions as Mode 1 and Mode 2. See pages 44 through 47 for further information. If the number of skin-friction surfaces is input as zero (NS=0 on the Type 9 card), no Type 11 cards will be used. (See sheet 6, page C-7 for the skin-friction input flow chart).

Card Type	Column	Code	Explanation
11	1-2	$IS_{I,1}$	Surface number = 1 to 10. Surface numbers need not be in order (right-justified integer).
	3	$IS_{I,2}$	Surface type flag. This flag controls the selection of the method to be used in calculating the local flow properties (in conjunction with the flag in CC 4) (integer). = 0 A flat plate will be assumed. Methods available in CC 4 will be used. = 1 If the surface is in compression, the local flow conditions will be found by the tangent-cone method. Inviscid-viscous interaction effects calculated will include a correction to account for tangent-cone pressures (rather than tangent-wedge).

Card Type	Column	Code	Explanation
11	4	$IS_{I,3}$	Flag to identify pressure calculation method and upper- or lower-surface identification. The available methods and identification flags are listed below. This flag is used in conjunction with the flag in CC 3 to control the local flow-calculation method. For Mode 1 skin-friction operation all surfaces must be indicated as being lower surfaces. (Integer) a. Oblique shock in compression and Prandtl-Meyer in expansion. = 1 Upper surface = 2 Lower surface b. Oblique shock in compression and Newtonian + Prandtl-Meyer in expansion. = 3 Upper surface = 4 Lower surface c. Newtonian + Prandtl-Meyer in both compression and expansion. = 5 Upper surface = 6 Lower surface Note: When CC 3 = 1, tangent-cone replaces oblique shock in the above options.
	5	$IS_{I,4}$	Skin-friction summation flag. (Integer) = 0 Use turbulent-skin-friction data in summation with pressure forces. = 1 Use laminar-skin-friction data in summation with pressure forces. (Note: The Program will make a switch to laminar summation at very low Reynolds number, where turbulent results are not meaningful.)
	6	$IS_{I,5}$	Use of angle of attack of the vehicle in the skin-friction calculations. This input card column is used only for Mode 2 skin-friction operation. For Mode 1 operation leave blank or input 0. = 0 Yes - incorporate vehicle angle of attack (see CC 35-40 for methods). = 1 No - do not use vehicle angle of attack.

Card Type	Column	Code	Explanation
11	7	$IS_{I,6}$	Wall-temperature and skin-friction method. Flag. The program always calculates both laminar and turbulent skin-friction results. The result to be added to the pressure calculations is indicated by the flag in CC 5. In the discussions below the methods to be used for laminar and turbulent flow are separated by a slash (i.e., Laminar/Turbulent). (Integer)

= 0 Calculate wall temperature and skin friction using Reference Temperature/Spalding-Chi methods.

= 1 Use adiabatic wall temperature and Reference Temperature/Spalding-Chi methods.

= 2 Use input wall temperature and Reference Temperature/Spalding-Chi Methods. T_w input in CC 47-52 & 53-58.

= 3 Calculate wall temperature and skin friction using Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods.

= 4 Use adiabatic wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods.

= 5 Use input wall temperature and Reference Enthalpy/Spalding-Chi (with enthalpy ratios) methods. T_w input in CC 47-52 & 53-58.

= 6 Calculate wall temperature and skin friction using Reference Temperature/Reference Temperature methods.

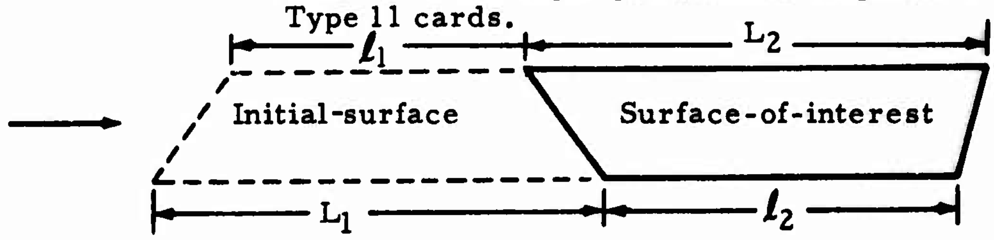
= 7 Use input wall temperature and Reference Temperature/Reference Temperature methods. T_w input in CC 47-52 & 53-58.

= 8 Calculate wall temperature and skin friction using Reference Enthalpy/Reference Enthalpy methods.

= 9 Use input wall temperature and Reference Enthalpy/Reference Enthalpy methods. T_w input in CC 47-52 & 53-58.

Card Type	Column	Code	Explanation
11	8	$IS_{I,7}$	Flag to control printing of skin-friction data for each skin-friction surface (integer). = 0 Do not print skin-friction data. = 1 Print skin-friction data. This is the recommended option for most applications.
	9	$IS_{I,8}$	Print flag for flow characteristics before and after the shock or expansion (integer). = 0 Do not print flow characteristics. = 1 Print flow characteristics. This is the recommended option for most applications.
	10	$IS_{I,9}$	Program iteration and local skin friction print flag (integer). = 0 Do not print iteration results for equilibrium temperature or final local skin-friction data. = 1 Print iteration results for wall temperature and the final local skin-friction data. = 2 Print the final local skin-friction data (iteration results are not printed). This is the recommended option for most applications.
	11-19	$SURF_{I,1}$	Surface wetted area in same units as S_{ref}. For Mode 1 operation (IGTYPE = 2 on the Type 2 card) the skin-friction surface wetted area is input in this location. If the wetted area is input as = 0.0 the program will use the surface area as calculated from the input geometry for each skin-friction element in the SDATA subroutine. For Mode 2 type of operation (IGTYPE = 0 on the Type 2 card) this input location must not be = 0.0. In Mode 2 operation the input surface area may be negative to subtract out a skin-friction surface. For Mode 2 the input wetted area must be for the complete vehicle (both left and right side) since the program will not account for the reflection of the geometry because of symmetry considerations. This is not the case for Mode 1 operation since the program will calculate data for the reflected portions if the symmetry considerations require it. For Mode 1 operation the input wetted area must correspond to the input skin-friction geometry data (i.e., if the Symmetry flag is = 0, left side of vehicle input, then the input wetted area should be only for the left side).

Card Type	Column	Code	Explanation
11			The four input quantities in CC 20 through 46 furnish to the program the planform shape of the skin-friction surface being analyzed ("Surface-of-interest"), and the shape of the initial-surface (to account for the fact that the flow has traversed some other part of the shape before reaching the surface of interest). This information is not obtained from the input skin-friction geometry data input on the Type 3 cards. The input skin-friction geometry data are used only to establish the position and orientation of the centroid of each skin-friction surface. The diagram below illustrates the input parameters required on the Type 11 cards.



Card Type	Column	Code	Explanation
11	20-28	$SURF_{I,2}$	For Mode 1 operation (IGTYPE = 2 on the Type 2 card) input the longest length of the surface-of-interest (L_2 in the diagram above). Feet. For Mode 2 operation input the longest length of the skin-friction surface. This mode does not provide for an initial surface as does Mode 1.
	29-34	$SURF_{I,3}$	For Mode 1 operation (IGTYPE = 2 on the Type 2 card) input the longest length of the initial-surface (L_1 in the diagram above). Feet. For Mode 2 operation (IGTYPE = 0) input the angle that the skin-friction surface makes with the vehicle reference plane (α_i) - deg. See Mode 2 for CC 35-40.
	35-40	$SURF_{I,4}$	For Mode 1 operation (IGTYPE = 2) input the taper ratio of the initial-surface (ℓ_1 / L_1). This taper ratio is defined as the ratio of the shortest chord length to the longest chord length. If both the initial-surface longest-length and the longest length of the surface-of-interest are on the same edge of the shape, then the taper ratio of the initial-surface is input as a positive number. If these lengths are on opposite sides of the shape such as in the diagram above then the initial surface taper ratio is input as a negative number. With these ground rules the absolute value of the taper ratio will never be greater than 1. 0.

Card Type	Column	Code	Explanation
11	35-40	$SURF_{I,4}$	(Continued) For Mode 2 operation input the skin-friction surface wedge angle in this location, deg. For Mode 2 operation the input data in CC 6, 29-34, 35-40, and 41-46 are sufficient to specify the orientation of the skin-friction surface with respect to the free-stream direction. The position of the surface is not required since the aerodynamic moment contributions due to the skin-friction shear forces are not calculated when Mode 2 is used. The equations used in calculating the flow deflection angle (ANGLE1) are given below. If CC 6 = 1, then the surface wedge angle (α_w) input in this location is the flow deflection angle (ANGLE1). If CC 6 = 0, then for an upper surface (as specified in CC 4) the flow deflection angle is calculated by $$ANGLE1 = \alpha + \alpha_i - \alpha_w$$ If CC 6 = 0, for a lower surface, then the flow deflection angle is calculated by $$ANGLE1 = \alpha + \alpha_i + \alpha_w$$
	41-46	$SURF_{I,5}$	For Mode 1 operation input the taper ratio of the surface-of-interest (ℓ_2 / L_2). This taper ratio is defined as the ratio of the shortest chord length to the longest chord length. This taper ratio is always positive and never greater than 1.0. For Mode 2 operation input taper ratio of skin-friction surface (tip chord/root chord).
	47-52	$SURF_{I,6}$	Input wall temperature for laminar calculations, °R. This input used when CC 7 = 2, 5, 7, or 9.
	53-58	$SURF_{I,7}$	Input wall temperature for turbulent calculations, °R. This input used when CC 7 = 2, 5, 7, or 9.
	59-62	$SURF_{I,8}$	Prandtl-Meyer-expansion correction factor (η_{C_T}) to be applied to Newtonian + Prandtl-Meyer pressure calculations in the skin-friction calculations. See CC 26-30 on the Type 12 card.
	66-68	CASE	Case number, not used by program (integer).
	72	TYPE	Card Type number = 11 (integer).
	77-80	SEQ	Sequence number used to keep the cards in proper order (not used by the program), integer.

Flight Attitude Data Card - This card controls the vehicle flight attitude (angle of attack and sideslip angle), data for the calculation of the surface pressures, and force-calculation method flags. The number of Type 12 cards is input on the Type 9 Flight Condition Card (CC 61-62). This number of Type 12 cards must be present unless the flag in CC 63 of the Type 9 card has been set = 1. The Type 12 cards are always loaded directly behind the center-of-gravity card (Type 10) when there are no skin-friction cards (Type 11), and behind the skin-friction cards when they are present (see sheet 7, page C-9).

Card Type	Column	Code	Explanation
12	1-6	ALPHA	Angle of attack (α) - Angle of attack of the vehicle reference line (deg.).
	7-12	BETA	Sideslip angle (β) - Positive with the wind striking the right side of the vehicle (deg.).
	13-18	CPSTAG	Modified Newtonian correlation factor (K). Always put a realistic value for K in this location even though the Modified Newtonian pressure calculation method is not being used. For shock-detachment conditions this parameter is required in the Newtonian + Prandtl-Meyer option provided as a default for this situation. Alternate uses for this input location are = Input pressure coefficient in impact areas when IMPACT = 11. = f_n (normal momentum accommodation coefficient) when IMPACT = 10. f_n = 0.0 for Newtonian and 1.0 for completely diffuse reflection. = Blast wave equation control flag when IMPACT = 15. Input 0.0 to use axisymmetric equation and 1.0 to use plane flow equation.
	19-25	QRP	Vehicle rotation rate (radians/sec.). = q (pitch rate) or = r (yaw rate), depending upon the value of the derivative flag in CC 45. This does not have to be a small value.

Card Type	Column	Code	Explanation
12	26-30	ETAC	This location is used for several different input parameters depending upon the value of the impact pressure calculation flag (IMPACT). = Prandtl-Meyer-expansion correction factor η_c in the following equation. Usually = 1.0. $$C_p = \frac{P_{\eta_c} - P_\infty}{q_\infty}$$ = Input pressure coefficient in shadow regions when ISHAD = 8. = T_B/T_∞ for IMPACT = 10. T_B/T_∞ is the ratio of body temperature to free-stream temp. = For IMPACT = 15 (blast wave) and axisymmetric flow, input $\sqrt{C_D} \cdot d$ (square root of drag coefficient times the sphere diameter). For plane flow, input $C_D^{2/3} \cdot d^{2/3}$ (where C_D is the drag coeff. of a cylinder and d is the cylinder diameter).
	31-35	ENPM	Surface slope modification factor. If input as $\neq 0.0$ the surface slope (θ, angle between outward surface normal and velocity vector) will be divided by this number. The impact angle (δ) is calculated as follows: $$\delta = \pi/2 - \theta_{input}/ENPM$$ If ENPM is input as = 0.0 or 1.0 then the body slope is not changed. This location has an alternate use when IMPACT is input as = 10. = f_t (tangential momentum accommodation coefficient, = 0.0 for Newtonian flow and 1.0 for completely diffuse reflection). When IMPACT = 15 use this location to input X_o for use in the blast wave equations.
	36-40	QQINF	Dynamic pressure (q) at the surface divided by the free stream q. $$C_{p_\infty} = C_p \left(q/q_\infty\right)$$ Must be input as 1.0 if no change from free stream is to be made. This parameter is useful in removing the effect of a vehicle component or in changing the local q because of interference from other components. This factor is not applied to skin-friction force contributions under Mode 2 skin-friction operation but it is used to alter the skin-friction shear force for Mode 1 type of skin-friction operation.

Card Type	Column	Code	Explanation
12	41-42	IMPACT	Impact force-calculation method flag. The following methods are available for calculation of pressures on surface elements in impact flow (right-justified integer).

= 1 Modified Newtonian (K is input in CC 13-18).

= 2 Modified Newtonian + Prandtl-Meyer (CC 26-30 must contain the proper value for η_c).

= 3 Tangent-wedge (using oblique-shock tables).

= 4 Tangent-wedge empirical.

= 5 Tangent-cone empirical.

= 6 OSU Blunt-Body Empirical (K must be input in CC 13-18).

= 7 Van Dyke Unified Method (small disturbance theory).

= 8 Blunt-body skin-friction shear-force contributions to the aero forces. The deck set-up is just like a regular pressure calculation run. The aero forces obtained must be added to the forces calculated using one of the other force calculation methods (usually modified Newtonian).

= 9 Shock-expansion Method (strip theory). IORIEN on Type 2 card may be = 0 or 1. For control surfaces (IGTYPE = 1) IORIEN must be = 1.

=10 Free-molecular flow. Input f_n in CC 13-18, f_t in CC 31-35, and T_B/T_∞ in CC 26-30. See Volume II free-molecular discussion.

=11 Input pressure coefficient (use CC 13-18 for the pressure coefficient).

=12 Hankey flat-surface empirical.

=13 Delta-wing empirical.

=14 Dahlem-Buck empirical.

=15 Blast-wave pressure increments. See CC 13-18, 26-30, 31-35, for additional input parameters.

=16 Modified tangent-cone.

Card Type	Column	Code	Explanation
12	41-42	IMPACT	(Continued)

=17 Boundary-layer induced pressures. This method calculates the vehicle force increments caused by the boundary-layer displacement effects. The deck set-up for this option should be exactly as for the skin friction option using IGTYPE =2, except that an IMPACT = 17 and ISHAD = 10 will cause the program to calculate induced pressure forces rather then the skin-friction forces. The force contributions calculated by this method should be added to the results obtained from regular inviscid pressure calculations (using summation capability on the Type 1 card). Since this method requires all the skin-friction data (Type 11 cards), it should be used only with skin-friction geometry elements input on the Type 3 cards.

43-44 ISHAD

Shadow force-calculation method flag. The following methods are available for calculation of pressures on surface elements in shadow flow (right-justified integer).

= 1 Newtonian (i.e., $C_p = 0.0$).

= 2 Modified Newtonian + Prandtl-Meyer (CC 26-30 must contain the proper value for η_c).

= 3 Prandtl-Meyer expansion from free-stream.

= 4 OSU blunt-body empirical (K must be input in CC 13-18).

= 5 Van Dyke Unified Method (small disturbance).

= 6 High Mach number base pressure ($C_p = -1/M^2$).

= 7 Shock-expansion (strip theory). See IMPACT = 9 discussion.

= 8 Input pressure coefficient (use CC 26-30 for the input pressure coefficient).

= 9 Free-molecular flow. See IMPACT =10 for other input requirements.

= 10 Boundary-layer induced pressures. See IMPACT = 17 for complete requirements.

Card Type	Column	Code	Explanation
12	45	IDERIV	Derivative flag — This flag controls the calculation of stability derivatives. (Integer)
			= 0 No stability derivatives are to be calculated directly by the program. Derivatives may be obtained by manually taking the slopes from the coefficient data.
			= 1 Derivatives with respect to angle of attack will be calculated: C_{L_α}, C_{m_α}, etc.
			= 2 Derivatives with respect to sideslip angle will be calculated: C_{Y_β}, C_{n_β}, etc.
			= 3 (Reserved for roll-derivative calculations - MARK III Mod 0 program does not have this capability.)
			= 4 Control-surface derivatives - C_{L_δ}, C_{m_δ}, etc. This component of the vehicle must be a control-surface component, with all the geometry input properly. This option will cause a large increase in machine time.
			= 5 Dynamic derivatives in pitch - C_{M_q}, C_{A_q}, etc. This option will also give alpha derivatives, C_{M_α}, etc. The plunge derivative will be calculated if the plunge derivative flag has been set.
			= 6 Dynamic derivatives in yaw - C_{Y_r}, C_{n_r}, etc. This option will also give beta derivatives, C_{Y_β}, C_{N_β}, etc. The derivative $C_{Y_{\dot\beta}}$ will also be calculated if the plunge derivative flag has been set.
	46	PRINT	Print flag - This flag controls the printing of the detailed force contributions of each vehicle element (integer).
			= 0 Do not print detailed element force data.
			= 1 Print detailed force contributions of each vehicle element (a large amount of output will be produced and machine time will increase). This option is recommended for at least one angle of attack when the shock-expansion force method is used.

Card Type	Column	Code	Explanation
12	47	IPRINT	Print Shock-Expansion Calculations flag — This flag controls the printing of detailed shock-expansion calculations (a large amount of output is produced) (integer). = 0 Do not print detailed shock-expansion calculations. = 1 Print shock-expansion calculations.
	48	NW	Wall temperature calculation method flag for use in control-surface separation calculations (only used when IGTYPE = 1). This input parameter is the same as the $IS_{I,6}$ parameter (CC 7) of the Type 11 skin-friction cards. If NW = 2, 5, 7, or 9 the wall temperature must be input in CC 62-65 of the Type 12 card.
	49-50	IMPACI	Impact method for Shock-Expansion calculations. This flag controls the method to be used in the calculation of the pressure and local properties on the first element of each streamwise strip for subsequent shock-expansion calculations. The available methods are listed below. This is used only when IMPACT = 9 or when control-surface component is being used (right-justified integer). = 3 Tangent-wedge (oblique shock) = 5 Tangent-cone empirical = 13 Delta-wing empirical
	51-52	ISHADI	Shadow method for Shock-Expansion calculations. This flag controls the method to be used in the calculation of the pressure and local properties on the first element of each streamwise strip for subsequent shock-expansion calculations (if the first element is in a shadow region). This is used only when ISHAD = 7 or when a control-surface component is being used. The only acceptable method at the present time is = 3 Prandtl-Meyer expansion from free stream (right-justified integer)
	55-59	DELTE	Control-surface deflection δ_e. Positive deflection is a movement of the surface out into the free stream - deg., (use only when IGTYPE =1 or 3).

Card Type	Column	Code	Explanation
12	58-61	RETRAN	Boundary-layer-transition Reynolds number to be used in control-surface flow-separation calculations. Number input is Reynolds number in millions, i.e. RETRAN = 1.0 would be 1.0×10^6. To force program to use laminar flow, input a large number (9999). To force the use of turbulent flow, input RETRAN =0.0. To give surface pressures without flow-separation effects input RETRAN = - 1.0 .
	62-65	TWALL	Input wall temperature when IGTYPE = 1 and NW in CC 48 is = 2, 5, 7, or 9. °R.
	66-68	CASE	Case number - not used by the program (right-justified integer).
	71-72	TYPE	Type code - 12 (integer).
	77-80	SEQ	Sequence number used to keep cards in proper order (not used by the program) (right-justified integer).

Plunge Derivative Data

These data cards are used in calculating the dynamic derivatives $C_{m_{\dot{\alpha}}}$ and $C_{Y_{\dot{\beta}}}$. This option may be used at the direction of either the IABDOT parameter on the Element Data Title Card (used when calculating plunge derivatives based on summation data), or the IABDOT control on the Flight Condition Card (used when derivatives are to be based on component data). A new (fresh) entry to the plunge derivative part of the program must be made for each type of calculation required (wing, tail, body, $C_{m_{\dot{\alpha}}}$, or $C_{Y_{\dot{\beta}}}$) (see sheet 9, page C-11).

Card Type	Column	Code	Explanation
14	1	IPART	Component type identification flag. = 1 wing = 2 body = 3 tail
	71-72	TYPE	Card type number = 14
	77-80	SEQ	Card sequence number (not used by program)
15	1-10	AR	Wing aspect ratio
	11-20	LAMBDA	Wing taper ratio (tip chord/root chord)
	21-30	M	$\text{Cot}\Lambda_{LE}$ (cotangent of leading-edge sweep angle)
	31-40	SWBYS	Ratio of exposed wing area to reference wing area
	41-50	CWBYC	Mean aerodynamic chord of exposed wing
	51-60	S	Exposed wing semispan
	61	K	Flag to control equation to be used in calculation K_{BW} (interference factor for effect of body in presence of wing). = 0 input value of K_{BW} on Type 16 card = 1 use slender-body theory (NACA TR 1307 eq. 21) = 2 half-planform is a trapezoid, NACA TR 1307, Eq. 24 for supersonic leading edge Eq. 26 for subsonic leading edge

Card Type	Column	Code	Explanation
15	61	K	= 3 Rectangular planform, Eq. 27 of TR 1307
			= 4 Triangular planform, TR 1307 Eq. 28 subsonic leading edge Eq. 29 supersonic leading edge
			= 5 Half-planform is a trapezoid (no afterbody for wing) Eq. 30 supersonic leading edge Eq. 31 subsonic leading edge
	71-72	TYPE	Card type number = 15
	77-80	SEQ	Card sequence number
16	1-10	CR	Wing root chord
	11-20	R	Body radius at wing root
	21-30	BETA	Prandtl-Glauert factor, $\sqrt{\text{Mach}^2 - 1}$
	31-40	CLALW	Lift-curve slope for wing (per radian)
	41-50	CMWPR	Wing-alone pitching-moment derivative
	51-60	KBW	Interference factor for effect of body in presence of wing
	71-72	TYPE	Card type number = 16
	77-80	SEQ	Card sequence number
17	1-10	AR	Tail aspect ratio
	11-20	LAMBDA	Tail taper ratio
	21-30	M	Cot Λ_{LE} (cotangent of leading-edge sweep angle)
	31-40	SWBYS	Ratio of exposed tail area to referenced wing area
	41-50	GAMMAT	Tail dihedral, deg.
	51-60	S	Tail semispan
	61	K	(See type 15 card at CC 61.)
	71-72	TYPE	Card type code = 17
	77-80	SEQ	Card sequence number

Card Type	Column	Code	Explanation
18	1-10	CR	Tail root chord
	11-20	R	Body radius at tail root
	21-30	BETA	Prandtl-Glauert factor
	31-40	CLALW	Lift-curve slope for tail (per radian)
	41-50	UPWASH	Tail upwash derivative caused by the wing
	51-60	XBTBYC	Tail length divided by reference chord
	71-72	TYPE	Card type number = 18
	77-80	SEQ	Card sequence number
19	1-10	KBW	Interference factor for effect of body in presence of tail
	11-20	Q	Tail effectiveness ratio
	71-72	TYPE	Card type number = 19
	77-80	SEQ	Card sequence number
20	1-10	VOLUME	Body volume
	11-20	SFRONT	Body frontal area
	21-30	LENGTH	Body length
	31-40	XO	Position of center of gravity
	41-50	XC	Area centroid location of body
	51-60	C	Body reference length
	71-72	TYPE	Card type number = 20
	77-80	SEQ	Card sequence number
21	1-10	VOLUME	Body volume
	11-20	SFRONT	Body frontal area
	21-30	B	Wing span (yawing-coefficient reference length)
	71-72	TYPE	Card type number = 21
	77-80	SEQ	Card sequence number

Thrust Vector Data Cards — These cards are used to provide input thrust-vector data for conversion to aerodynamic coefficients. Thrust-vector capability may be used at two different times as desired. First, thrust-vector data may be input at the time that saved data is being added under the control of the data summation flag. Second, thrust-vector data may be input after all the angle-of-attack data for a given component have been calculated (see sheet 10, page C-11).

Card Type	Column	Code	Explanation
22	1-11	F	Force-vector magnitude, pounds.
	11-16	XCENT	X-coordinate of vector point of application.
	17-22	YCENT	Y-coordinate of vector point of application.
	23-28	ZCENT	Z-coordinate of vector point of application.
	29-34	NX	Direction cosine of force vector in X-direction (positive when vector is pointing in the X direction).
	35-40	NY	Direction cosine of force vector in Y-direction (positive when vector is pointing in the Y direction).
	41-46	NZ	Direction cosine of force vector in Z-direction (positive when vector is pointing in the Z direction).
	60	LAST	Last vector card control flag = 0 This is not the last vector card = 1 This is the last vector card
	62	IPRINT	Print flag = 0 Do not print vector data = 1 Print vector results
	71-72	TYPE	Card type number = 22
	77-80	SEQ	Card sequence number (not used by program).

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GEOMETRY DATA

Several options are available for describing the geometric shape of a vehicle or component for use in this program. These methods are selected at the discretion of the user. A given vehicle may be defined by a combination of the methods. These methods permit the user to describe a completely arbitrary shape, or to synthesize a vehicle from simple component parts, depending upon the requirements of the problem. The general techniques used in achieving this are outlined below.

In the Mark III Program the geometry data are input in one of the following forms.

1. Surface-element method (distributed elements). This method uses a large number of surface coordinate points that are related in groups of 4 to form a surface element. The program then converts the area defined by each set of 4 points into a plane quadrilateral element. All types of input geometry data eventually end up in this form before actual force computations are made.

2. Elliptical-cross-section data. In this method the input data consist of the necessary radii, circle or ellipse center, and the sector of the circle or ellipse to be used. The program then converts these data into exactly the same surface-element form as described in the above paragraph. These data created by the program are in the correct format for conversion to plane quadrilaterals for subsequent calculations. The element geometry data generated in this method are stored on the geometry data storage tape (Tape 8).

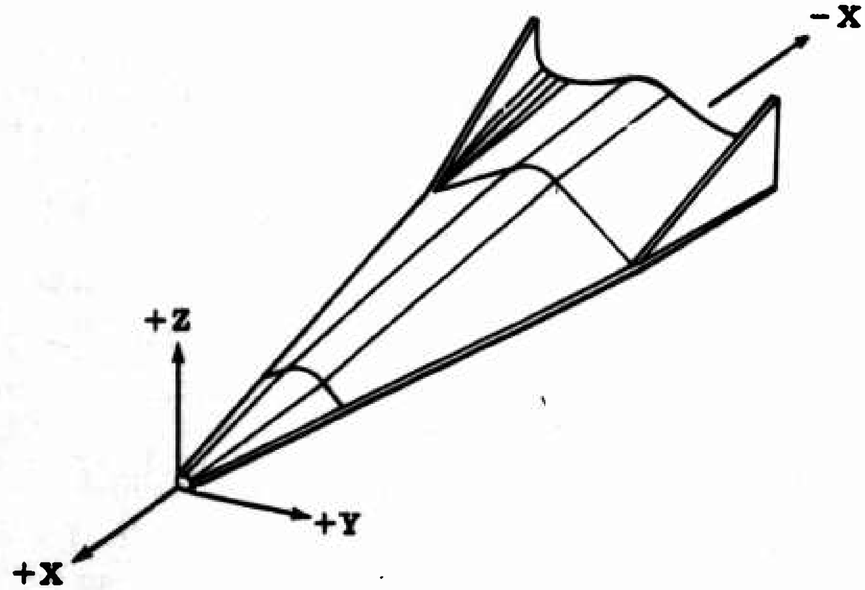
3. Mathematical surface fit (Parametric Cubics). The surface input data for this method consist of coordinates of points along the four boundaries of a patch. The coefficients for a mathematical surface fit equation are then calculated to provide a description of the interior surface of the patch. This surface is then converted to exactly the same form as in method 1 by a systematic variation of the two parametric parameters. Again, as in method 2 above, the resulting element data are saved on the geometry storage tape for subsequent conversion to plane quadrilaterals.

4. External Surface Generation Program. In this method the geometry data in element form are generated by some surface generation program external to the AERO program. The Slab Delta Generation Program is one such program.

The selection of the method to be used in describing a shape depends upon the detailed requirements of the problem and the vehicle shape. For completely arbitrary shapes either the surface element or the parametric cubic method would be used. For simple shapes, such as a vehicle nose, leading edge, or circular or elliptical cross section, the elliptical-surface generation method (method 2) would be used. For a vehicle synthesized from a number of simple components the geometry data can be generated by a separate program, just as has been done for the slab delta.

The important result of this general approach to the geometry problem is that the force-calculation part of the program is not affected by the method used to input the geometric shape. The form of the geometry data can be varied to meet the situation.

The coordinate system used for all the geometry data is shown in the figure below. For symmetrical vehicles it is standard practice to input the left side of the vehicle only.



Since all of the geometry options finally produce geometry data in surface-element form, it is important that the methods and nomenclature used with this method be clearly understood. It is, therefore, recommended that the input instructions for the surface-element method be studied before an attempt is made to use either the ellipse or the parametric cubic options.

Under certain circumstances, the input geometry data must be input in a prescribed manner. This occurs when using the shock-expansion pressure-calculation method or when analyzing a control-surface component. A discussion of these problems is presented on pages 98 and 99, and may be referred to after the basic-geometry input methods are understood.

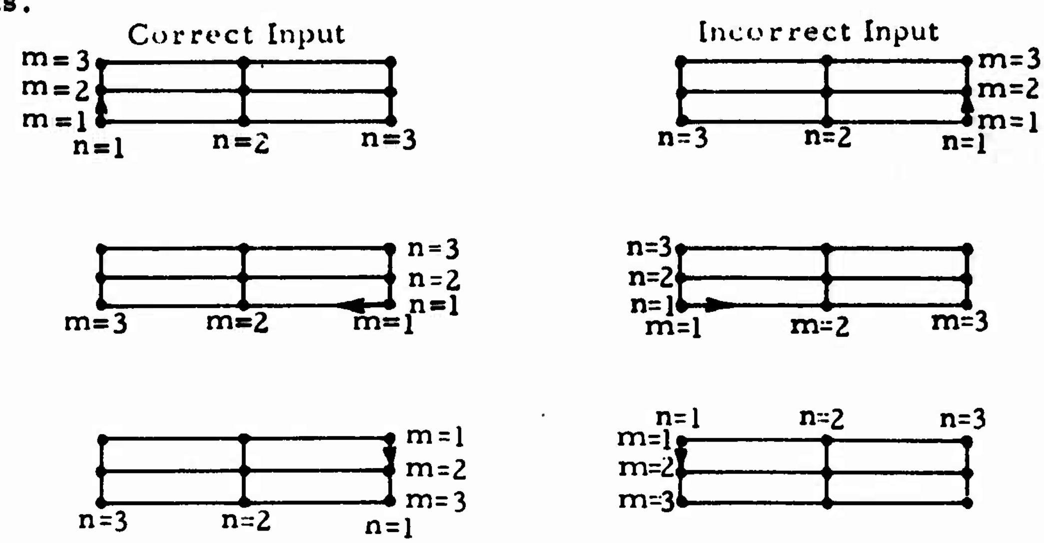
Surface-Element Input Data (Distributed-Element Method)

The geometric input data in this method include the coordinates of a large number of points on the vehicle surface. The input data are organized in a

manner that permits the description of a vehicle on a component-buildup basis. This gives increased flexibility in shape description and makes it possible to use different force-calculation methods for different components. Because of possible changes in the surface contours of a component, it may also be necessary to divide the component into several sections. Each section of a vehicle component is further divided into a number of small units called elements, each defined by four points in space. In practice, the surface coordinates are usually recorded from cross-section drawings of the vehicle in such a way that each point need be read only once (even though it may be a member of as many as four adjacent elements). Each point is defined by its three coordinates and a STATUS flag that indicates whether it is the first point of a new section, a continuation of a column of points, the beginning of a new column, or the last point of the vehicle. The program uses the STATUS flags to determine how the input points are to be related to form elements, and how the elements are combined to form a section.

The first question that the user asks when starting to load the element geometry is, "In what order do I enter the surface points?" The basic rules to be followed are given below. These will be followed by a discussion of a visual technique that many users will find helpful in determining the proper loading order.

For the purpose of organizing the input data for computation, each point is assigned a pair of integers, m and n. These integers are not actually input to the program (they are calculated internally) but their use in the following discussion will provide a better understanding of the input-data organization. For each point, n identifies the "column" of points to which it belongs, and m identifies its position in the "column," i.e., the "row." The first point of a "column" always has m = 1. To insure that the program will compute outward normal vectors, the following condition for the order of input points must be satisfied. If an observer is located in the flow and is oriented so that locally he sees points on the surface with m values increasing upward, he must also see n values increasing toward the right. Strict adherence to this simple rule will always lead to a correct set of input geometry data. Examples of correct and incorrect input are shown in the sketches below. In these pictures the flow field lies above the paper, and the interior of the body lies below the paper. The arrows indicate the order of reading the points.



Associated with each input point is an input quantity called its status. The first point of each new section has Status = 2. Except for the first n-line of a section, the first point of each n-line has Status 1. The last point of the component of the vehicle has Status 3. All other points have Status = 0, i.e., they may be left blank on the input sheet. The program will not exit properly from the surface-data subprogram and into the force-calculation phase until it reads a Status = 3.

The simple visual technique described below is helpful in determining the proper order of the input points.

1. First, assume that you are holding in your hand a small model of the vehicle shape. Many program users find it helpful to construct a small paper model to help in visualizing the geometry loading procedure. On this model we will draw lines to represent the elements to be loaded for a given vehicle section. This process is illustrated in the photographs in Figure 16.

2. Next, decide which strips of elements are to constitute "columns" and which "rows." In most problems one of two procedures is selected – either a "column" of elements starts at the bottom of the shape and continues around to the top, roughly following vehicle cross-section lines, or a "column" is oriented so that it starts at the front part of the vehicle and runs aft toward the rear.

3. Hold the model out in front of you and rotate it until the columns are vertical with the first row of elements at the bottom. This procedure should be used regardless of what part of the vehicle is being loaded – the body, fin, inside of fin, etc. Always orientate the model so that you are looking at the section to be loaded (from the outside, looking at the surface) with the columns running vertical and the rows running horizontal.

4. Now that you have the section being loaded oriented in front of you, with the columns vertical, apply the following cardinal geometry rule:

   - If a column of data points are loaded from the bottom to the top, then the next column of points (starting with a Status = 1) must be to the right.

All of the geometric input data for this geometry option are input on Type 3 Element Data cards. Each card contains the X, Y, Z coordinates and Status flag for two points on the body surface. Every card in the element-geometry deck must contain two surface points except the last card, which may have only the first-surface-point coordinates and status filled in. If a particular line of vehicle points is odd in number then it is usually advisable to repeat the last point (a dummy point) so that the last card will have two sets of point data. This permits the shifting of vehicle sections of the deck without disrupting other sections.

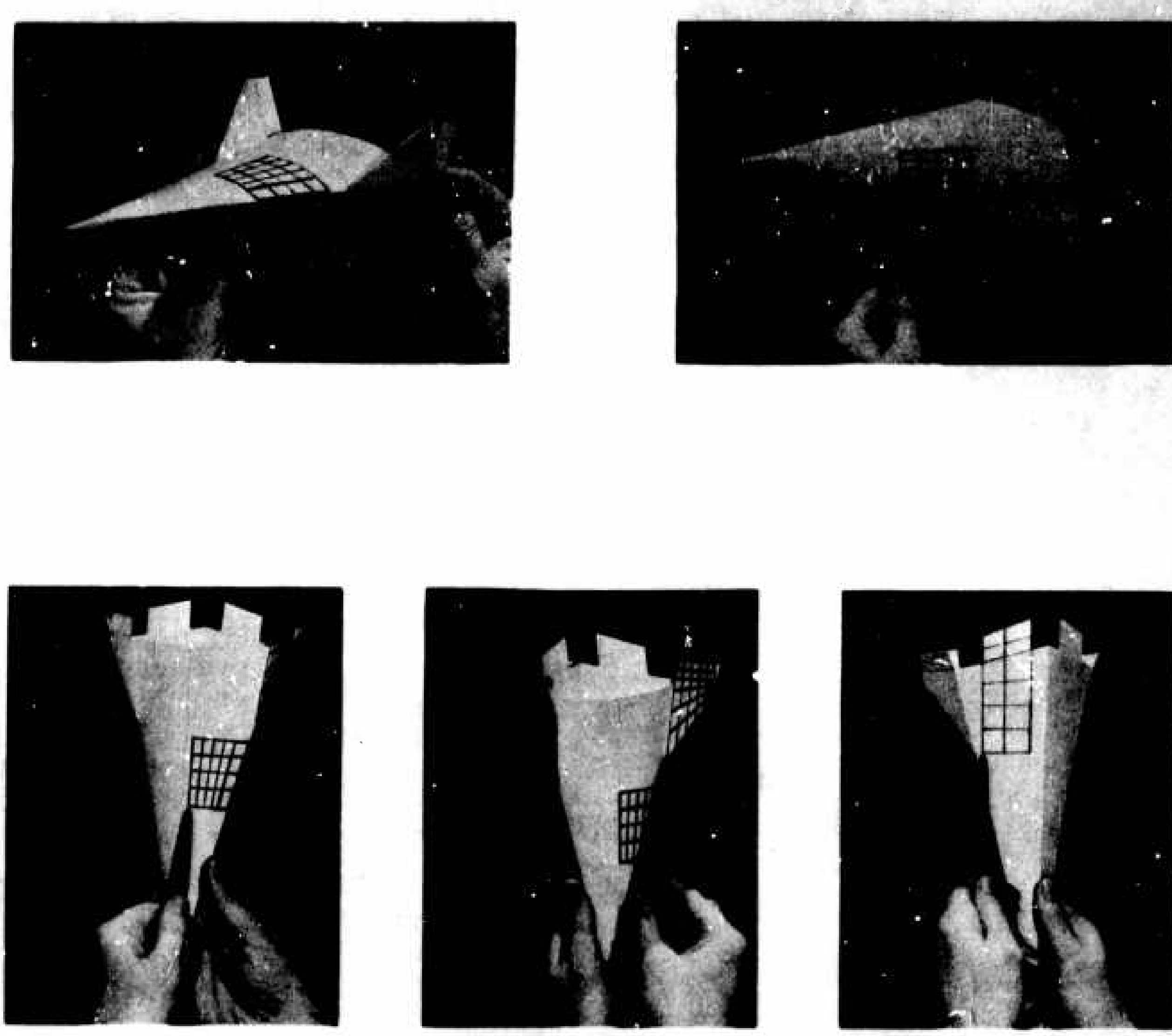


Figure 16. Use of Small Paper Model in Visualizing Geometry Loading Procedure. (In each example the pen is pointing at the first point to be loaded and in the direction of the first column of input points.)

Note that if the element data is being converted into quadrilaterals for force calculations, then the last status flag must be = 3. During the reading of surface-element geometry data from tape 5 or from tape 8 (as controlled by the flag ITAPE on the Type 2 Element Data Control Card) the program will continue to read cards until it finds a status flag = 3. Activity in the Surface data subroutine (SDATA) will then stop and control transferred back to the main AERO program. The next card after an element-data card with STATUS = 3 must always be a Type 8 Force Data Title card.

The detailed description of the input data for the surface-element method is presented below (see sheet 3, page C-5).

Element Data Input Cards

Card Type	Column	Code	Explanation
3	1-10	X	X-coordinate of surface point (the value of X is written anywhere in this space with a decimal point and sign; usually input only if it is negative).
	11-20	Y	Y-coordinate of surface point
	21-30	Z	Z-coordinate of surface point
	31	STAT	Status flag for the above set of coordinates (=2, 1, 0, or 3).
	32-41	XX	X-coordinate of surface point
	42-51	YY	Y-coordinate of surface point
	52-61	ZZ	Z-coordinate of surface point
	62	STATT	Status flag for the above set of coordinates (=2, 1, 0, or 3).
	66-68	CASE	Case number (right-justified integer)
	69-70	SECT	Numbers or letters to identify the vehicle section. These must be legal machine characters.
	72	TYPE	Card type number = 3
	77-80	SEQ	Card sequence number. This number is used to identify each card of a particular section and to aid in keeping the cards in order (right-justified integer).

Elliptical-Crcss-Section Data

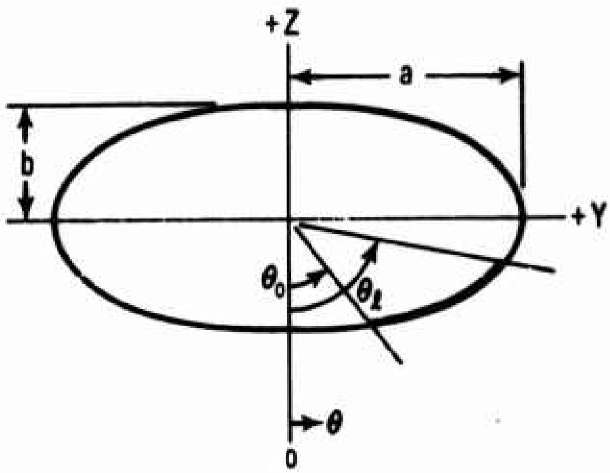
This geometry option provides the capability of generating geometric data for vehicle components having whole or partial circular or elliptical cross sections with a minimum amount of input information required. This option is usually used to generate hemispherical noses and wing and tail leading edges.

The data generated by this option is saved on the geometry storage tape (Tape 8) in normal surface-element input data form. In this manner it is possible to describe a vehicle with a combination of both hand-input data (in surface-element or parametric-cubic input form) and analytically derived circular or elliptical cross-section data.

The input data for this geometry option is described below. Input sheet 5 is used for these data. The input procedure is to define the basic properties of a circular or elliptical cross section (a cut in the Z-Y plane with X being a constant for the cross section). Each cross section where a set of element data is desired must be input in this manner. The first cross section must be toward the front of the vehicle, and each suceeding section must be toward the rear. See sheet 4, page C-5.

Ellipse Generation Control Card

Card Type	Column	Code	Explanation
4	1-48	TITLE	Vehicle section or component title. Any acceptable machine characters.
	60	DISCON	Angular-data option flag. This flag controls the angular division of the cross section and the dummy points generated to give complete card output for the geometry storage tape. See sketch below.

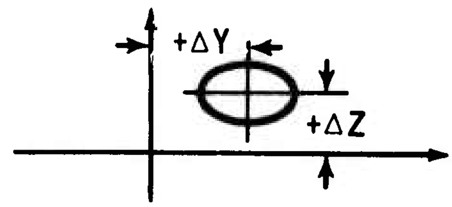


Card Type	Column	Code	Explanation
4	60	DISCON	The angular-data options are given below. = 1 All initial angles, θ_0, and all final angles, θ_ℓ, are the same for each cross section for this section of the vehicle. = 2 All θ_ℓ in the vehicle section are the same but the θ_0 varies. = 3 All θ_0 in the vehicle section are the same but the θ_ℓ varies.
	61	IPRINT	Print flag. This flag controls the printing of the element data generated in this option. This data printout will contain the exact information written on the geometry storage tape. = 0 Do not print data = 1 Print
	66-68	CASE	Case number. A right-justified integer used to identify the vehicle data.
	69-70	SECT	Section identification. A number or letter used to identify this section or component of the vehicle. Any acceptable machine characters.
	72	TYPE	Card Type number = 4 (integer)

Cross-Section Data Cards (one card for each cross-section cut desired)

Card Type	Column	Code	Explanation
5	1-10	X	X-station (usually negative if the vehicle nose is at the coordinate system origin).
	11-16	THETO	Initial angle, θ_0. Degrees
	17-22	THETL	Final angle, θ_ℓ, Degrees
	23-25	NN	Number of divisions of cross section desired. This number controls the number and spacing of the elements generated between θ_0 and θ_ℓ. Right-justified integer.
	26-35	A	Ellipse radius along the Y-axis, a.
	36-45	B	Ellipse radius along the Z-axis, b.
	46-52	DELZ	Offset of center of ellipse in the Z-direction, ΔZ.

Card Type	Column	Code	Explanation
5	53-59	DELY	Offset of center of ellipse in the Y-direction, ΔY.



Card Type	Column	Code	Explanation
	60	LAST	Last Flag. This flag controls the Status flag (STATT) of the last element point generated and the position of the geometry data storage tape (Tape 8) after the element data has been written on it.

= 0 This is not the last cross section; set STATT = 0 and read in new cross-section card.

= 1 This is the last cross section; no more cross sections are provided, set last STATT = 0, write end of file (EOF) on geometry storage tape (Tape 8) and return to the surface data routine. Note that since the last status flag STATT = 0 rather than = 3, that quadrilaterals cannot be calculated for this vehicle section. The Element Data Control card (Type 2) must contain a "5" in CC 61, and the next Force Data Title card should contain a "1" in CC 60.

= 2 This is the last cross section for this vehicle section or component. Set the status flag STATT = 0, and read in a new ellipse data title card.

= 3 This is the last cross section; no more sections are provided, set last STATT = 3, write end of file on geometry tape, and backspace the tape (Tape 8) by the number of records written for this vehicle component. The surface-data routine will now be able to read this data and convert into quadrilaterals for use in the force calculations.

= 4 This is the last cross section; no more sections are given, set last STATT = 3, write end of file on geometry tape, but do not backspace Tape 8 as in the above option.

Card Type	Column	Code	Explanation
	72	TYPE	Card Type number = 5 (integer)

Parametric-Cubic Input Data

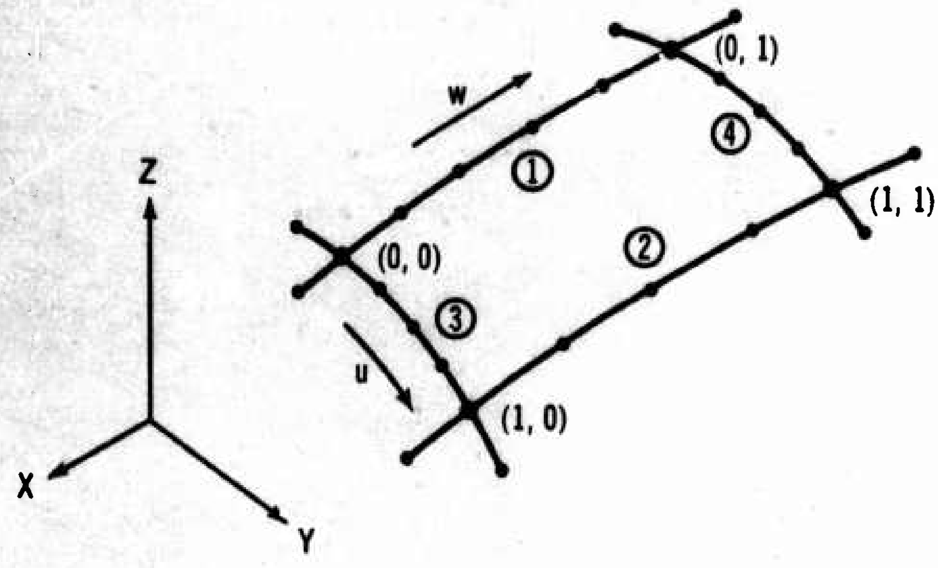
The geometry-input option is provided as an alternate input method in the description of arbitrary shapes. In this respect, it serves the same purpose as the surface-element input method.

In the surface-element input method a vehicle section is described by a large number of surface points organized in an element fashion. In the Parametric Cubic method only points along the boundaries of a patch are input to the program and the distributed surface points (surface elements) required for the subsequent quadrilateral calculations are determined by the program.

The basic features of this method are that (1) fewer input points are required to describe a shape, (2) the input of this data is a little more complicated, and (3) the generated element size is controlled by two input parameters and may be changed to meet the requirements of the problem.

The input data for this option uses input data sheet 5. The input data consist of points along the four boundaries of a patch. The program calculates the coefficients for a mathematical surface-fit equation to provide a description of the interior surface of the patch. This surface is then converted into exactly the same form as the normal surface-element input data for further calculations. The element data generated is saved on the geometry storage tape (Tape 8) for use in other phases of the program.

The figure below illustrates how a section is described by this method.



Each of the four boundaries is identified in this figure by a number inside a circle. The input data for each of these boundaries must be input in the order indicated by these numbers, i.e., boundaries 1, 2, 3, and 4. The order of the input points on a boundary and the order of the boundaries is very important. The approach to insure a correct input of the data is similar to that used for the quadrilateral-element input data. First, the user should imagine that he is holding a small model of the vehicle in his

hand. The vehicle is divided into a number of sections or patches. The figure on the previous page represents one such patch. Our objective here is to describe how the data for one patch is loaded into the program.

The user orientates the model of the vehicle so that the number 1 boundary is to the left and the number 2 boundary to the right. Coordinates of points along the number 1 boundary are loaded first. The order of these points (from the user's view of the model) is from the bottom to the top of the patch. Note that a point must be included outside the patch at either end of the boundary to give proper slopes at the corner points. The next input points are for boundary number 2 and again from bottom to top. Boundary number 3 is loaded from left to right as is boundary number 4. A different number of points may be used to describe each boundary up to a maximum of 20 for each one.

Each of the input points has a status flag associated with it similar to that used in the surface-element input method. The first point (the bottom point outside the patch on boundary number 1) has a status of 2. The first point on each of the other boundaries has a status of 1. All the other points have a status of 0 except the last point (the point on the right side outside the patch on boundary 4) which has a status of 3.

The input sheet contains two points per card. Every card must contain two points except the last which may have one point (loaded on the left side of the card).

The detailed input information required for this geometry-method option is presented below.

Parametric Cubic Title Card — This card contains patch control data and divisions to be used in converting the patch to element data. (see sheet 5, page C-7)

Card Type	Column	Code	Explanation
6	1-48	TITLE	Section or patch title. Any acceptable machine characters.
	50-52	NOU	Number of division of the parametric variable u. This controls the number of elements in the element mesh in the u-direction (right-justified integer).
	54-56	NOW	Number of divisions of the parametric variable w. This controls the number of elements in the element mesh in the w-direction (right-justified integer). If this number is an even number then the program will change it to the next higher odd number so that there will always be an odd number of elements in a column. This will give an even number of points in a column to fill out both the left and right sides of the element data card.

Card Type	Column	Code	Explanation
6	60	LAST	Last Flag. This flag controls the Status flag (STATT) of the last element point generated and the position of the geometry data storage tape (Tape 8) after all data has been written on it. = 1 This is the last patch. Set the last-point status flag STATT = 0, write end of file on the geometry storage tape, and return to the surface-data routine. = 2 This is not the last patch. Set the last-point status flag STATT = 0, and read in a new set of patch data (including a new title card). = 3 This is the last patch. Set the last-point status to STATT = 3, write an end of file on tape 8, and backspace tape 8 by the number of cards written. The tape will be in the proper position for use by the surface-data subroutine. = 4 This is the last patch. Set the last-point status to STATT = 3, write an end of file on tape 8, but do not backspace tape 8 before returning to the surface data subroutine.
	61	ISOVR	First-point status override flag. = 0 The status flag for the first coordinate point of the patch will be = 2 (normal mode). = 1 The status flag for the first coordinate point of the patch will be set = 1. This will permit "joining together" several parametric cubic patches to form a single section of surface-element data.
	62	IPRINT	Print flag. This flag controls the printing of the element data generated in this option. This data printout will contain the exact information written on the geometry storage tape (in BCD card image form). = 0 Do not print data = 1 Print
	72	TYPE	Card Type number = 6 (integer)

Parametric Cubic Boundary Data -- This card contains the coordinates of the boundary curves for a parametric cubic patch. (See sheet 5, page C-7)

Card Type	Column	Code	Explanation
7	1-10	X	X-coordinate of boundary curve point
	11-20	Y	Y-coordinate of boundary curve point
	21-30	Z	Z-coordinate of boundary curve point
	31	STAT	Status flag for the above set of coordinates (=2, 1, 0, or 3). This flag controls the reading in of the boundary curve data and is not the same as the STATUS flag that will be generated and written on the geometry storage tape along with the generated surface element data.
	32-41	XX	X-coordinate of boundary curve point
	42-51	YY	Y-coordinate of boundary curve point
	52-61	ZZ	Z-coordinate of boundary curve point
	62	STATT	Status flag for the above set of coordinates (=2, 1, 0, or 3). This flag controls the reading in of the boundary curve data and is not the same as the STATUS flag that will be generated and written on the geometry storage tape along with the generated surface element data.
	66-68	CASE	Case number (right-justified integer)
	69-70	SECT	Numbers or letters to identify the vehicle section. These must be legal machine characters.
	72	TYPE	Card type number = 7
	77-80	SEQ	Card sequence number (right justified integer).

Special Geometry Problems

There are several application areas where the geometry data must be prepared in a prescribed manner before successful solutions can be obtained. These areas are discussed briefly below.

Shock-Expansion Geometry Preparation. The use of the shock-expansion pressure-calculation method places certain requirements on the input geometry data. This is basically caused by the fact that the program does not calculate stream-lines on the surface but merely applies the shock-expansion process on each strip of elements, element by element. This means that the elements themselves become the streamline directions as far as the program is concerned. This means that the user must decide as he is loading the geometry just where the streamlines are to go. This is quite simple and acceptable where two-dimensional surfaces are involved, or for axisymmetric bodies at small angles of attack. It is for these reasons that the shock-expansion pressure method should only be applied to these simple types of shapes and should not be used on some complex, completely arbitrary three-dimensional shape.

When using the shock-expansion pressure method each section of the vehicle should be handled as a separate individual section. The explanation for this requires a review of the procedure used in the shock-expansion calculation. First, we know that a section of the vehicle can be orientated in two basic modes - in a normal cross-section mode with the first input column of elements stretching around the vehicle from the bottom to the top, or in a strip fashion with the first input column of elements starting at the front and running aft along the shape. On the Element Data Control Card these are identified by the orientation flag as IORIEN = 0 or = 1 respectively.

Next, when the program starts to make the shock-expansion calculations it must decide which set of input elements represent the starting point for the shock-expansion process (these elements are termed the section "leading elements"). If the flag IORIEN = 0, then the section is in the normal cross-section orientation so the first input column of elements becomes the starting elements for the shock-expansion calculations and the "rows" of elements are assumed to define the streamline direction. If the flag IORIEN $\geq$ 1, then the strip input method is used and the first element of each strip (the first row of elements) becomes the leading element.

It is important to note that the program will always start the shock-expansion calculations with the "leading elements" of a section, even though these elements may not be a physical surface leading edge (such as a wing leading edge). This is the usual occurrence in many applications. This shortcoming may be easily solved by a simple geometry loading technique. The basic trick is to make the leading elements of a section (that are to be used in a shock expansion) have the same angle relative to the flow as the physical leading edge does.

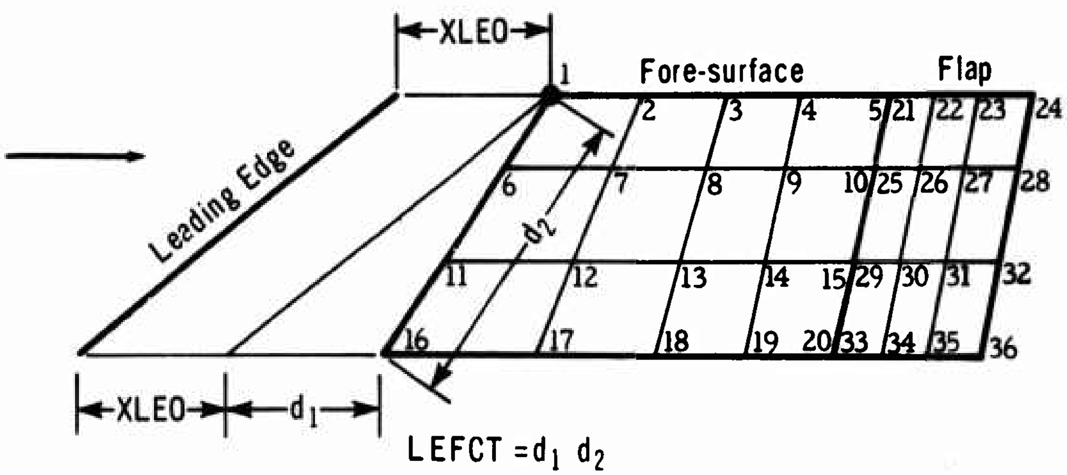
A simple example of this is the flat lower surface of a re-entry vehicle where the flow expands from the forward ramp to the aft flat surface. For this case let us assume that on the forward ramp we are using oblique-

shock pressures (tangent wedge), but that we wish to use shock-expansion for the turn at the corner between the forward ramp and aft flat surface. In this case we would take a very narrow column of elements in the forward ramp just ahead of the corner and make this column the leading elements for the aft flat.

A similar useful trick is to make the leading elements have whatever shape is required to give the proper starting conditions for the shock-expansion, but make the elements so small that they themselves do not contribute a significant amount to the overall vehicle forces.

<u>Control-Surface Geometry Preparation</u>. Because of the complex nature of the control-surface flow-separation problem it is necessary to impose certain rules on the geometry data to be used. First, every control-surface vehicle component must consist of two geometry sections. The first section loaded must be for that part of the vehicle in front of the control flap where flow-separation effects will be felt (the flap "fore-surface"). The elements must be input in a strip-wise manner with IORIEN ≥ 1 on the Element Data Control Card. The next section loaded must be the flap itself, also with strip-wise orientation, and with the same number of stream-wise strips as used for the fore-surface. The total number of elements in a streamwise strip, including both the fore-surface and the flap, cannot be greater than 125.

The computation of flow separation effects requires knowledge of the boundary layer running length to each element. Since the leading elements on the fore-surface may not correspond to the physical surface leading edge it is necessary to provide some additional information to permit the calculation of the required running lengths. These data are provided by the parameters LEFCT and XLEO on the Type 2 Element Data Control Card. The determination of these two input quantities is illustrated in the figure below. When control surface data are to be analyzed the geometry data must be in feet, or scale factors must be used to convert the dimensions to feet. The numbers on the diagram below indicate the numerical order of the input points. Points 1 and 21 have a STATUS of 2. Points 6, 11, 16, 25, 29, and 33 have a STATUS of 1. Point 36 has a STATUS of 3. All other points have a STATUS of 0.



PICTURE DRAWING PROGRAM

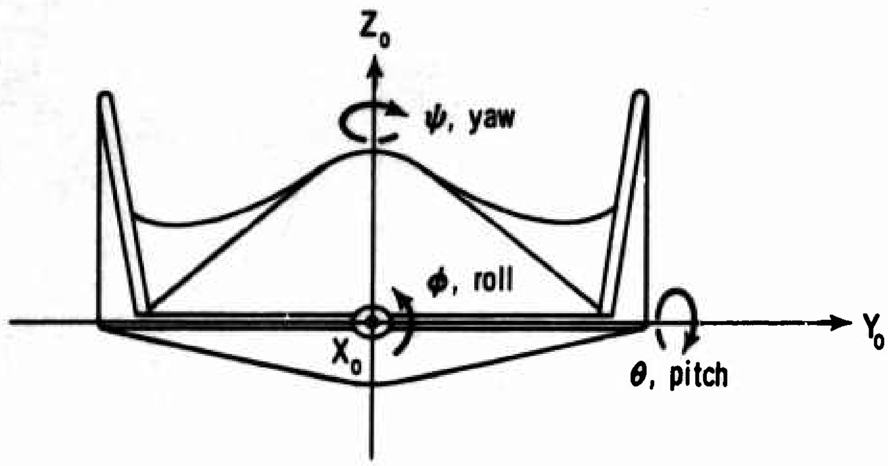
This phase option is used in checking the input geometry data for errors. It is also used to visualize the geometric shape as it is to be used by the force-calculation option.

The Picture Drawing Program accepts the geometry in element data form and, with the use of certain picture-generation data, produces an output tape for processing on the SC-4020 recorder. The element data is read either from the normal input Tape 5 or from the geometry storage Tape 8. The output tape from this program, when processed on the SC-4020 automatic recorder, will produce pictures of the vehicle at the selected viewing angles. Any errors in the data will be immediately evident upon viewing these pictures. This is illustrated in Figure 2. These errors can then be corrected before the data is submitted to the program for the aerodynamic calculations.

The picture drawing program can also be used to obtain a detailed printout of the properties of each quadrilateral element of the vehicle. The normal output of this program also includes the accumulated surface area and the number of elements for each section of the vehicle.

This program may be operated alone with the element data as part of the input, or it may be run after the AERO program or the Slab Delta Program and obtain the element data from the geometry storage tape (Tape 8).

To create the vehicle pictures each surface point must be rotated to the desired viewing angle and transformed into a coordinate system in the plane of the paper. With zero rotation angles the body coordinate system is coincident with the fixed system in the plane of the paper. This coordinate system is illustrated below.



The rotations of the body and its coordinate system to give a desired viewing angle are specified by a yaw-pitch-roll sequence (ψ, θ, ϕ). A small toy airplane model is useful in visualizing the yaw, pitch, and roll angles required to give a desired view of a vehicle.

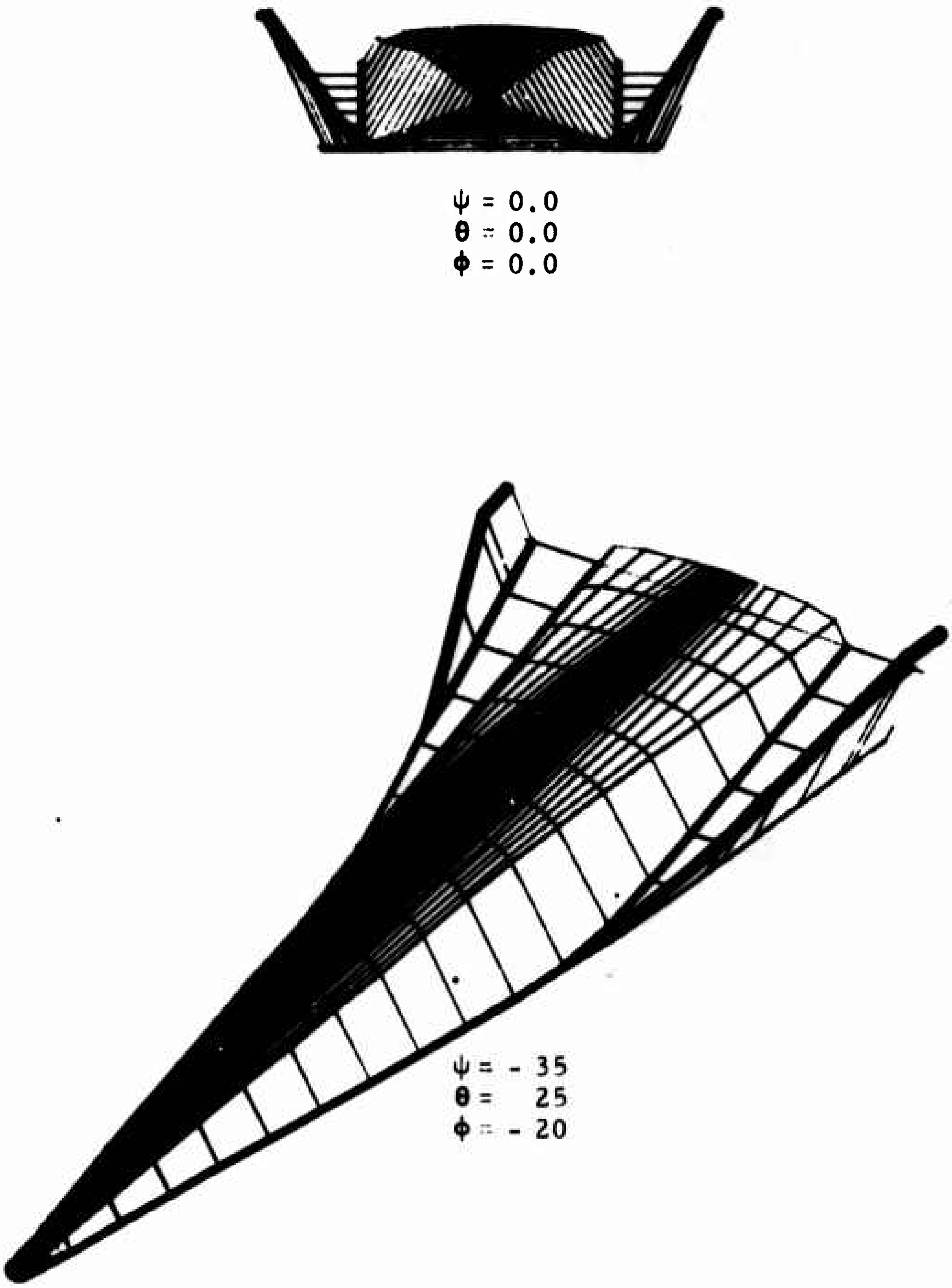


Figure 17. Selection of Viewing Angles for Pictures

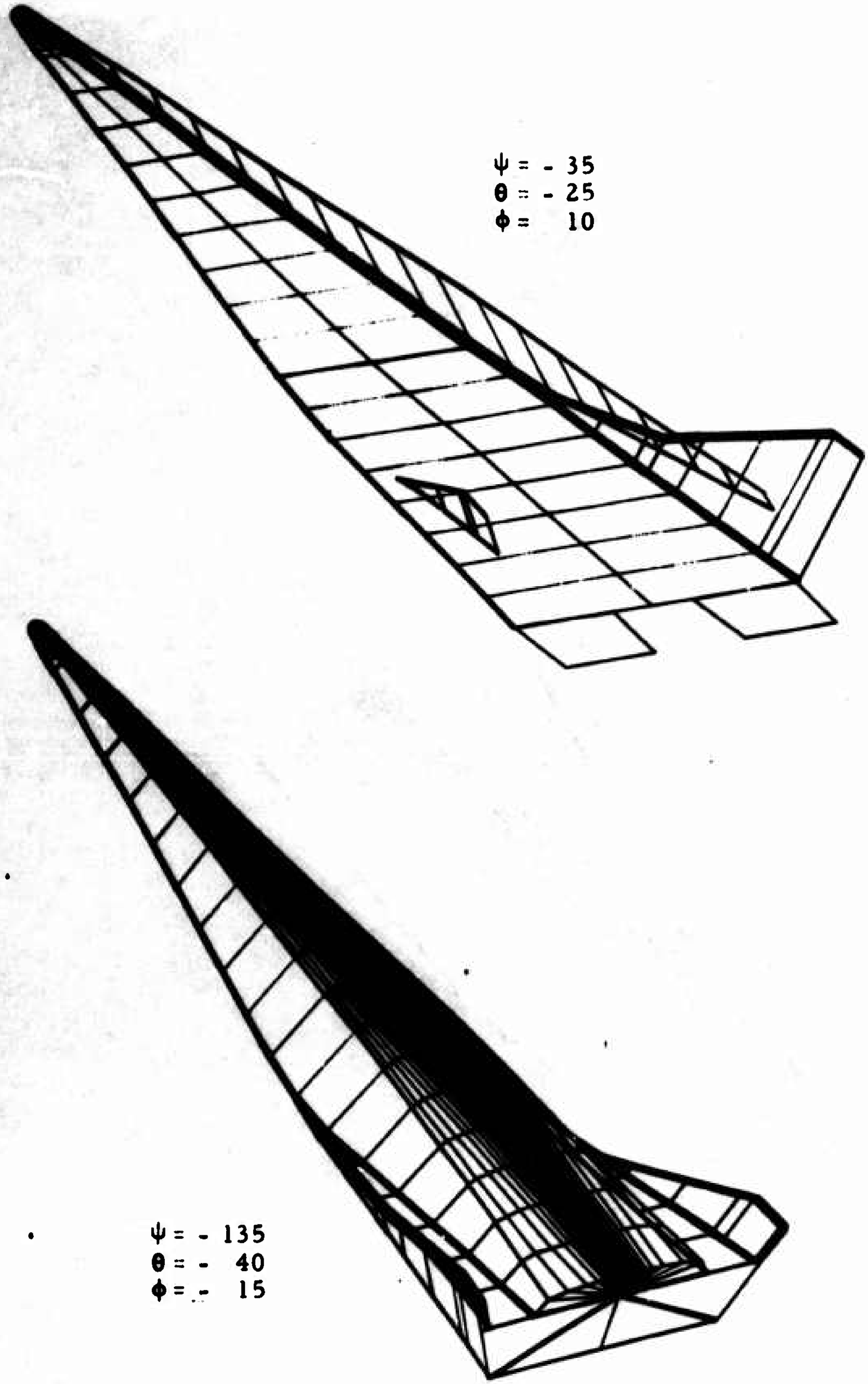


Figure 18. Selection of Viewing Angles for Pictures

The most frequently used views are: front view (=0, =0, =0), top-front view (-35, 25, -20), bottom-front view (-35, -25, 10), and top-rear view (-135, -40, -15) (see Figures 17 and 18).

The input data to this program consists of the geometry-element data and the necessary plotting instructions. The geometry data may also be read directly from the geometry storage tape generated by the AERO Program or by the Slab Delta Program. The detailed input instructions are presented below.

Element Data Title Card - See sheet 11, page C-13, and the input data chart on page C-21.

Card Type	Column	Code	Explanation
31	1-59	TITLE	Vehicle identification or title for this run. Use any acceptable machine characters.
	66-68	CASE	Case number. Not used by the program (right-justified integer).
	71-72	TYPE	Type number = 31
	77-80	SEQ	Sequence number for use in keeping cards in proper order. This number is not read by the program (right-justified integer).

Element Data Control Card - This card controls the reading of the geometry data.

Card Type	Column	Code	Explanation
32	1	PRINTS	Print flag to control the printing of detailed characteristics of each quadrilateral element (integer). = 0 Do not print element characteristics = 1 Print element characteristics
	3	SYMFCT	Symmetry flag (same as for AERO Program, see page 57). All the components of a single vehicle must have the same Symmetry flag to give a complete picture of the shape. = 0 For a vehicle symmetrical about the X-Z plane.
	4	IORIEN	Element orientation. See CC 4 of Type 2 card for a complete description. Values of IORIEN of 0 or 1 have no effect on the Picture Program. Values of 2 or 3 will give correct pictures when the data-point-slip methods are used to input the geometry data. Vehicle components with different values for IORIEN cannot be drawn correctly on a single picture frame.

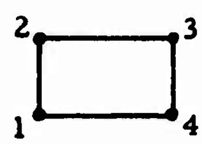
Card Type	Column	Code	Explanation
32	5	IFACT	Scale-factor flag (integer). This flag tells the program when it is to use the scale-factor data given by the input parameters in CC 7 through 43. These factors are frequently used to move the vehicle so that its center corresponds approximately to the coordinate-system origin. For a vehicle with its nose at X = 0.0 this is accomplished by using a DELX value of about one-half of the vehicle length. This simplifies the selection of picture scales to keep the vehicle within the picture frame. = 0 Use input geometry coordinates (no scale factors will be used). = 1 Use scale factors to scale and shift the geometry data in the basic coordinate system (the original geometry data on tape 5 or tape 8 are not changed since the scale factors are applied in the quadrilateral calculation process). The data are changed using the following type of equation for X, Y, and Z. $X_{new} = X_{input} \cdot (XSC) + DELX$
	7-12	XSC	Scale factor to be multiplied by X_{input}.
	13-18	YSC	Scale factor to be multiplied by Y_{input}.
	19-24	ZSC	Scale factor to be multiplied by Z_{input}.
	26-31	DELX	ΔX, increment to be added to $X_{input} \cdot (XSC)$
	32-37	DELY	ΔY, increment to be added to Y_{input} (YSC)
	38-43	DELZ	ΔZ, increment to be added to $Z_{input} \cdot (ZSC)$
	60-61	ISTAT3	Number of Status = 3 in the vehicle geometry deck. The program will count the number of Status = 3 in the geometry deck and when the count reaches this input value, the program will assume that the last section of the vehicle has been read (right-justified integer).
	62	ITAPE	Geometry tape control flag. = 0 Geometry data (Type 3) will be read from Tape 5 (geometry data cards are loaded along with picture-data control cards). = 1 Geometry data (Type 3) will be read from the geometry storage tape (Tape 8).

Card Type	Column	Code	Explanation
32	63	IREW8	Flag to control the position of Tape 8 just before the geometry data are read from it. = 0 Rewind Tape 8 and then read geometry data from it. = 1 Do not rewind Tape 8, but start reading geometry data from it in its current position.
	66-68	CASE	Case number (right-justified integer).
	71-72	TYPE	Card Type number = 32 (integer).
	77-80	SEQ	Sequence number used to keep the cards in proper order (not used by the program) (right-justified integer).

33 Note: This card type number is not used by the program.

Picture Control Data Cards - These cards control the picture angles and scales. Each data card is identified by a type number in 71-72. A typical deck setup will consist of the above cards (types 31, 32) and as many picture control cards (Types 34, 35, 36, 37) as required. Each picture requires a set of picture data control cards.

Card Type	Column	Code	Explanation
34	1-6	PSI	Yaw angle, ψ, deg.
	8-13	THETA	Pitch angle, θ, deg.
	15-20	PHI	Roll angle, ϕ, deg.
	22	ICS	Point connect flag
			= 0 Connect all 4 points of each element
			= 1 Connect points 1-2 and 3-4 (see diagram below)
			= 2 Connect points 1-4 and 2-3
			= 3 Do not connect points with lines



Card Type	Column	Code	Explanation
	24	IREFL	Reflection-elements flag
			= 0 Do not plot elements reflected to negative side of Y-axis.
			= 1 Plot reflected elements
			= 2 Plot reflected elements (only one quadrant is input).
	26	ISHAD	Shadow element flag
			= 0 Do not plot elements that face away from the viewer (shadow elements).
			= 1 Plot shadow elements (see page 36).
	28	IAREA	Area print out flag
			= 0 Do not print section areas on the SC-4020 pictures.
			= 1 Print out the area of each section on the SC-4020 pictures. Use only when CC 32 = 2.

Card Type	Column	Code	Explanation
34	30	IQUAD	Quadrilateral plot flag = 0 Draw input elements. = 1 Draw picture using quadrilateral-element corner points.
	32	IFRAME	Frame-advance control flag = 0 Advance frame at end of plot of all vehicle elements. = 1 Advance frame at the end of each column of elements (only one Type 37 card required). = 2 Advance frame between each section of the vehicle (note that for this option one Type 37 card must be present for each picture frame to be produced).
	34-35	NCAM	Camera selection flag (right-justified integer). = 0 Use both cameras. = 9 Use 9-inch hard-copy camera only. = 35 Use 35 mm camera.
	37-38	MARKPT	Plotting-symbol code (right-justified integer). A few of the most frequently used symbols are listed below. (For a complete list see page 116). (blank) = 48 (use for most pictures) O = 38 · = 42 + = 16 * = 44 ◘ = 63
	41-43	NG	Emphasize every Nth vertical line (-0 when no grid is used)(right-justified integer). = - for square grid = + for rectangular grid = 0 if no lines are to be emphasized

Card Type	Column	Code	Explanation
34	44-46	MG	Emphasize every Mth horizontal line (= - 0 when no grid is used) (Right-justified integer) (see CC 41-43 for sign convention).
	48-50	IG	Label every Ith vertical grid line (=0 for no grid) (right-justified integer).
	51-53	JG	Label every Jth horizontal grid line (=0 for no grid).
	55-56	NXG	Number of characters in the number labels for the X-scale (include decimal point) (=0 for no grid) (right-justified integer).
	57-58	NYG	Number of characters in the number labels for the Y-scale (include decimal point). Up to 6 significant figures plus decimal point are permissible on the character labels (right-justified integer) (=0 for no grid).
	60	LAST	Last plot of case control flag = 0 This is not the last plot for this set of geometry data. A new Type 34 card is expected after the Type 37 card for this picture. = 1 This is the last plot for this set of geometry data. After the Type 37 card for this picture the program will expect to find a Type 31 Element Data Title card or the end of phase Type 99 card.
	66-68	CASE	Case number (not used by program).
	71-72	TYPE	Type number = 34
	77-80	SEQ	Sequence number used for keeping cards in order only (right-justified integer).

Grid Data Card

Card Type	Column	Code	Explanation
35	1-10	XLG	Value of left side of horizontal scale.
	11-20	XRG	Value of right side of horizontal scale.
	21-30	YBG	Value of bottom of vertical scale.
	31-40	YTG	Value of top of vertical scale.
	41-50	DXG	Increment for vertical grid-line spacing.
	51-59	DYG	Increment for horizontal grid-line spacing.

Card Type	Column	Code	Explanation
35	60	NOSCAL	No Grid Flag = 0 Include grid lines and scales (Type 36 card is required). = 1 Do not draw any grid lines or labels (Type 36 card not required).
	66-68	CASE	Case number (not used by the program).
	71-72	TYPE	Type number = 35.
	77-80	SEQ	Card sequence number.

Scale Label Card

This card is not required if CC 60 of the Type 35 card is = 1.

Card Type	Column	Code	Explanation
36	1-30	VTITLE	Vertical-scale label
	31-50	HTTITLE	Horizontal-scale label
	71-72	TYPE	Type number = 36
	77-80	SEQ	Card Sequence number

Plot Title Card

Card Type	Column	Code	Explanation
37	1-59	HLABEL	Title to be placed at the top of the picture (usually contains the vehicle name and the picture angles).
	66-68	CASE	Case number (not used by program).
	71-72	TYPE	Type number = 37.
	77-80	SEQ	Card sequence number

Note: if IFRAME = 0 or = 1, then only one card is used.

if IFRAME = 2, one Type 37 card must be present for each section of the vehicle.

The last card in the picture drawing must be a Type 99 phase termination card.

OUTPUT DATA PLOTTER PROGRAM

The Output Data Plotter Program is used to prepare plots of the aerodynamic coefficients calculated by the AERO program. Each time the AERO program prints out the aerodynamic force data it checks the flag, IPS, to see if the data are to be saved on the aerodynamic-characteristics plotting tape. If IPS = 1, then the aerodynamic data are written on to Tape 9. Also, the number of sets of data written is recorded on Tape 10. If data are calculated for 15 angles of attack and saved on Tape 9, then the number 15 will be written on Tape 10.

A large number of aerodynamic coefficients are calculated by the AERO program. Because of this, only the twelve most important ones are saved on the aerodynamic-characteristics plotting tape. These are α, C_D, C_L, C_A, C_Y, C_N, β, L/D, C_m, C_ℓ, C_n, C_f. If the user wishes to plot some other parameter then he could modify this list by changing the data WRITE statement for Tape 9 in subroutine AERO.

A flow chart describing the use of this program option is given on page C-23. The detail input instructions are also presented. Plotter Program Control Data is input using input sheet 12. Two examples of plotted data are shown in Figures 3 and 4 (pages 12 and 13).

Plotter Program Input Data

Data Source Control

Card Type	Column	Code	Explanation
41	1-4	NC	Control flag indicating the source of the data to be plotted (right-justified integer). = 0 Read from Tape 10 the number of angle-of-attack sets of data to be read from Tape 9. This is the normal input when plotting aerodynamic data. = NC The number of angle-of-attack sets of data to be read from the standard input Tape 5. = -1 No data will be plotted. Only the plot grid will be drawn.
	71-72	TYPE	Card Type number = 41
	77-80	SEQ	Card sequence number (not used by the program).

Vertical-Title Card

Card Type	Column	Code	Explanation
44	1-70	TITLE	Vertical-scale identification. Any acceptable machine characters.
	71-72	TYPE	Card Type number = 44
	77-80	SEQ	Card sequence numbers

Horizontal-Title Card

Card Type	Column	Code	Explanation
45	1-70	TITLE	Horizontal-scale identification. Any acceptable machine characters.
	71-72	TYPE	Card Type number = 45
	77-80	SEQ	Card sequence numbers

Plotting-Grid Data Card

Card Type	Column	Code	Explanation
46	1-10	W_1	X_{left} — value of left side of horizontal scale (real number).
	11-20	W_2	X_{right} — value of right side of horizontal scale (real number).
	21-30	W_3	Y_{bottom} — value of bottom of vertical scale (real number).
	31-40	W_4	Y_{top} — value of top of vertical scale (real number).
	41-50	W_5	ΔX — increments of X for vertical grid lines (real number).
	51-60	W_6	ΔY — increments of Y for horizontal grid lines (real number).
	71-72	TYPE	Card Type number = 46
	77-80	SEQ	Card sequence number

Plot Control Array Card (All inputs are right-justified integers.)

Card Type	Column	Code	Explanation
47	1-2	I_1	Identification of data array to be plotted on the horizontal scale (X-scale). For the Mark III Mod 0 program the following data are available.

Array Item	Parameter	Array Item	Parameter
1	α	7	β
2	C_D	8	L/D
3	C_L	9	C_m
4	C_A	10	C_ℓ
5	C_Y	11	C_n
6	C_N	12	C_f

Card Type	Column	Code	Explanation
	3-4	I_2	Identification of data array to be plotted on the vertical scale (Y-scale). See above list for array numbers.
	6	I_3	Film advance flag = 1 Advance film and put frame count in upper right corner. = 2 Do not advance film = 3 Advance film, but do not display frame count.
	8-10	I_4	Control to emphasize vertical grid lines. = 0 Lines will not be emphasized. = ±N Emphasize every Nth vertical line. If = - N, use square grid = + N, use rectangular grid
	11-13	I_5	Control to emphasize horizontal grid lines. = 0 Lines will not be emphasized. = ±M Emphasize every Mth horizontal line. If = - M, use square grid = + M, use rectangular grid

Card Type	Column	Code	Explanation
47	15-17	I_6	Control to label vertical grid lines. = ±I Label every Ith vertical grid line. If = +,numerical labels at 0.0 axis. = -,numerical labels outside of grid.
	18-20	I_7	Control to label horizontal grid lines. = ±J Label every Jth horizontal grid line. If = +, numerical labels at 0.0 axis. = -, numerical labels outside of grid.
	22-25	I_8	Number of points to be plotted. If this is input as 0, then the program will set it equal to the number of data points to be plotted as determined from Tape 10 or from the Data Source parameter on the Type 41 card. For normal plotting of data from AERO, set I_8 = 0.
	27-29	I_9	Δ subscript for selecting X-array data to be plotted. = 1 Plot all data points = 2 Plot every other point
	30-32	I_{10}	Δ subscript for selecting Y-array data to be plotted. = 1 Plot all data points = 2 Plot every other point
	34-36	I_{11}	Number of plotting characters to be used. = 1 For Mark II Mod 0 program
	38-39	I_{12}	Plotting symbol code (see page 116)
	41	I_{13}	Point connect flag = 0 Do not connect plotted points. = 1 Connect plotted points with a straight line.
	43-44	I_{14}	Camera select flag = 9 Nine inch hard-copy paper = 35 35mm film = 0 both

Card Type	Column	Code	Explanation
47	46	I_{15}	Control flag for next operation = 0 Stop and exit from PLOT after plotting these Y-vs-X data. = 1 Return to read card Types 44 through 47 for new plot. = 2 Return to read a new Type 41 card. = 3 Return to read Tape 10 for setting up next data arrays. Next card after Type 48 card(s) will be a Type 44 card. = 4 After this plot is complete, read new arrays from Tape 1. (A Type 44 card is required after the Type 48 card.) Note: If $I_{20} \neq 0$, then I_{15} is set = I_{21} for the nth block of repeated plotting.
	48-49	I_{16}	Maximum number of characters in number labels for X-scale (including decimal point). Up to 6 significant figures + decimal point. = + F format (i.e., 5.2) = - E format (i.e., $7.6 \times 10^{+02}$)
	50-51	I_{17}	Maximum number of characters in number labels for Y-scale (including decimal point). Up to 6 significant figures + decimal point. = + F format (i.e., 5.2) = - E format (i.e. $7.6 \times 10^{+02}$)
	53-54	I_{18}	Number of horizontal-label cards (Type 48) to be read. ($0 \rightarrow 64$). The first card would be printed at the top of the plot and the 64th at the bottom.
	56	I_{19}	Flag to control writing of data arrays onto Tape 1 for subsequent plotting. = 0 Do not save data arrays. = 1 Write data arrays on Tape 1.

Card Type	Column	Code	Explanation
47	58-59	I_{20}	Title and scale cards bypass flag.
			= 0 Next plot requires Type 44, 45, and 46 cards
			= N N-blocks of data will be plotted using only the first set of Type 44, 45, 46, and 47 cards.
	61	I_{21}	Control flag for next operation when $I_{20} \neq 0$. This flag serves the same function for the Nth block of data I_{15} does when $I_{20} = 0$.
	71-72	TYPE	Card Type number = 47
	77-80	SEQ	Card sequence number

Horizontal-Label Cards - (The number of these cards is specified by I_{18}.)

Card Type	Column	Code	Explanation
48	1-70	TITLE	Horizontal title for plot. Any acceptable machine characters. Up to 64 cards may be used. With a number of cards, some of them being blank in columns 1-70, plotted lines or points may be identified by labels.
	71-72	TYPE	Card Type = 48
	77-80	SEQ	Card sequence number.

CODE	PLOTTING SYMBOL	CODE	PLOTTING SYMBOL	CODE	PLOTTING SYMBOL
0	0	22	F	43	$
1	1	23	G	44	*
2	2	24	H	45	γ
3	3	25	I	46	~
4	4	26	π	47	δ
5	5	27	. (Period)	48	(Blank)
6	6	28	)	49	/
7	7	29	β	50	S
8	8	30	±	51	T
9	9	31	?	52	U
10	θ	32	-	53	V
11	=	33	J	54	W
12	"	34	K	55	X
13	' (Prime)	35	L	56	Y
14	•	36	M	57	Z
15	α	37	N	58	o (degree)
16	+	38	O (Letter)	59	,
17	A	39	P	60	(
18	B	40	Q	61	∫
19	C	41	R	62	[
20	D	42	(Dot	63	□
21	E				

SLAB DELTA PROGRAM

The Slab Delta Program option may be used to generate all of the surface-element data necessary for the aerodynamic analysis of this class of vehicle shape. This program option serves two purposes in this program. First, it can be used to make parametric studies of a large number of slab delta shapes with a minimum of time and effort. Second, it serves as a model to guide a user who wishes to program his own subroutine to facilitate the rapid analysis of some other family of simple shapes. The surface-element data generated by this option is recorded on the geometry storage tape (Tape 8) for use by the AERO Program and by the Picture Drawing Program. The input data required by this program option are discussed below.

Slab Delta Title Card (see sheet 13, page C-15, and page C-25.)

Card Type	Column	Code	Explanation
50	1-59	TITLE	Slab delta vehicle title
	60	LAST	Slab delta option termination flag = 0 This is not the last slab delta configuration. A new Type 50 Title Card will be expected after this slab delta is completed. = 1 The last slab delta has been completed. A Type 99 Phase Termination Card is required after the last Station Data Card.
	71-72	TYPE	Card type number = 50
	77-80	SEQ	Card sequence number

Card Type	Column	Code	Explanation
51	1-10	SWEEP	Slab-delta leading-edge sweep angle, degrees
	11-20	RNOSE	Nose and leading-edge radius
	21-23	THETAB	Number of angular division, $\Delta\theta$, to be used for the lower 90 degrees of the leading edge. Should be an even number. (Right-justified integer.)
	24-26	THETAT	Numer of angular divisions, $\Delta\theta$, to be used for the top 90 degrees of the leading edge. Should be an even number (right justified integer).
	27-29	NOSPAN	Number of element divisions to be generated on the flat bottom and flat top. Should be an odd number (right-justified integer).
	30	ITOC	Thickness correction factor flag = 0 Thickness tables are not input = 1 Thickness tables will be input (see page 119)
	31	MODE	Geometry mode flag = 1 Geometry for the top inboard of the leading edge is not generated. = 2 Basic slab delta with straight sides if thickness factors are used. = 3 If thickness factors are used, the top will be elliptical.
	36	IREW8	Tape 8 rewind flag = 0 Rewind Tape 8 before generating geometry. = 1 Do not rewind Tape 8.
	42	I8BSP	Tape 8 backspace flag = 0 Do not backspace Tape 8 after geometry has been written on it. = 1 Before leaving slab delta routine. backspace Tape 8 by the number of geometry cards written on it.
	48	IPRINT	Print control flag = 0 Do not print generated element card images. = 1 Print card images
	71-72	TYPE	Card Type number = 51
	77-80	SEQ	Card sequence number

Station Data Card

Card Type	Column	Code	Explanation
52	1-10	XB	X-station cut for generation of element data (visually input as negative).
	11-20	DELZ	Vertical displacement increment (shear factor), ΔZ
	21-30	TOPTC	Top thickness modification factor. This factor is multiplied times the + Z coordinates before the ΔZ shear factor is applied.
	31-40	BOTTC	Bottom thickness modification factor. This factor is multiplied times the - Z coordinates before the ΔZ shear factor is applied.
	42	ITOP	Top geometry control flag. = 0 A top flat will be included. = 1 No top flat will be generated.
	60	LAST3	Last-cross-section flag. = 0 This is not the last cross section for this slab delta. = 1 This is the last cross section. Set the last point Status flag = 3.
	66-68	CASE	Case number to be punched in geometry cards generated (right-justified integer).
	71-72	TYPE	Card type number = 54.
	77-80	SEQ	Card sequence number

SLAB DELTA THICKNESS-CORRECTION TABLES

These input data tables may be used to modify a basic slab delta with thickness increments that are both a function of X-station and of Y (semi-span coordinate). Since these tables are not used too often no standard input sheet has been prepared. However, the input requirements will be discussed below. The complete set of cards for the thickness-correction tables must be input right after the Type 51 card if ITOC = 1. The complete set of cards for the top is loaded first followed by a set for the bottom. The input tables use a triple interpolation technique where the third variable at the present time is a dummy.

ZFACT = fn (% Semi-span, XB, DUMMY)

The interpolation scheme uses a parabolic fit between sets of three input points. Only a minimum of input information will be given here

since it is assumed that the user will familiarize himself with the details of the Slab Delta Program before attempting to use this option.

The thickness-correction-table data will be input on Type 52 cards for the top and Type 53 cards for the bottom (in CC 71-72). Each card should contain 5 fields of 10 columns wide and the variable LAST2 in CC 66. The top data is stored in the ZT_I array (maximum size of 300) for the top, and the ZB_I array (also 300 in size) for the bottom. The required order of data is outlined below.

Array	Item
ZT_1	Number of semi span points
ZT_2	Number of XB stations
ZT_3	Number of DUMMY points = 3
ZT_4	Semi-span_1
ZT_5	Semi-span_2
ZT_6	Semi-span_3
.	Semi-span_{max}
.	$\text{DUMMY}_1 = 0.0$
	$\text{DUMMY}_2 = 0.0$
	$\text{DUMMY}_3 = 0.0$
	XB_1
	ZFACT at (XB_1, Semi-span_1, DUMMY_1)
	ZFACT at (XB_1, Semi-span_1, DUMMY_2)
	ZFACT at (XB_1, Semi-span_1, DUMMY_3)
	(Note all these ZFACT are the same, since all DUMMY = 0.0.)
	ZFACT at (XB_1, Semi-span_2, DUMMY_1)
	.
	.
	XB_2
	etc.

The last card in each table should contain 1 in column 60 to indicate the end of the table data.

INPUT DATA SUMMARY AND CHECK LIST

No computer program is capable of running itself — it takes a certain amount of intelligently and accurately prepared input data. This section of this report will review and summarize the concepts involved in preparing this input data for the Hypersonic Arbitrary-Body Computer Program System.

The flow of calculations within this program and the reading of the input data is controlled by a few important input flags. These flags are not input all at once at the beginning of the run but are spread throughout the different cards in the input deck. It is this feature that gives this program its great flexibility in solving a very wide variety of problems. The general philosophy of this approach can best be illustrated by several examples. During this discussion the reader should refer to the fold-out input sheet samples provided in Appendix C and also to the appropriate input data flow diagram.

1st Sample Problem Set-Up

Problem - Given a vehicle consisting of a flat plate described by the surface-element input method. Pressure forces on this shape are to be calculated at 5 angles of attack. No skin friction is to be calculated.

Solution - The values for the key input flags are given below (cards in order with only the values of the key control flags given).

Card

1 - System Control card — card column 3 = 1

2 - Element Data Title card — Type 1

ISUM = 0

3 - Element Data Control card - Type 2

IGEOM = 0 Element data is input.

ITAPE = 0 Geometry data is on normal input tape.

IGTYPE = 0 Not a flap.

IELOV = 0 Calculate quadrilaterals.

4 - Element Data Geometry Cards — Type 3 — As many Type 3 cards as required to describe the shape.

5 - Force Data Title card — Type 8

IRETI(CC60) = 0

Card

6 - Flight-Condition card — Type 9

LAST = 0 This is the last set of flight condition, c.g., and flight-attitude cards.

NUMBERα-β = 5 5 angles of attack.

USE OLDα-β = 0 Type 12 cards are input.

NO.S.F. = 0 No skin friction cards.

7 - Center-of-Gravity card — Type 10

8 - Flight-Attitude Data cards — Type 12
5 cards, one for each angle of attack

9 - Type 99 Phase Termination card

If skin-friction data were to be calculated for the above case (using Mode 2 of the skin-friction procedures), then the skin-friction (Type 11 cards) would be located between cards 7 and 8 and the number of Type 11 cards would be given in card columns 64-65 of the Flight Condition Card.

2nd Sample Problem Set-Up

Problem - Given a vehicle composed of two components. The first component is to be generated by the ellipse subroutine, and the second is hand input using the surface-element method. Calculate the inviscid pressure forces using a different force method on each component; print the resulting total inviscid characteristics; determine the skin-friction using Mode 1 of the skin-friction procedures (input skin-friction geometry on Type 3 cards); and print the total vehicle characteristics. Also, have the Picture Drawing Program draw pictures of the resulting vehicle.

Solution - The values for the key flags are given below (cards in order with only the values of the key control flags given).

Card

1 - System Control card — Type 0

Card Column 3 = 1 Aerodynamic program option

Card Column 6 = 2 Picture Drawing option

2 - Element Data Title card — Type 1

ISUM = 1 Save force contribution for future summation.

3 - Element-Data Control card — Type 2

IGEOM = 1 Use elliptical routine to generate shape.

Card				
3		ITAPE	= 1	For quadrilateral calculations read geometry data from Tape 8 after rewinding it.
		IGTYPE	= 0	Not a flap
		IELOV	= 0	Calculate quadrilaterals
4	-	Ellipse Generation Control card — Type 4		
		ANGLE FLAG	= 1	Starting and final ellipse angles are the same
		PRINT	= 1	Print ellipse-generated element data cards
5	-	Cross-Section Data cards for ellipse generation — Type 5		
		All cards except the last		
		LAST	= 0	This is not the last cross section.
		Last cross-section data card		
		LAST	= 3	This is the last cross-section card.
6	-	Force-Data Title card — Type 8		
		Return to Type 1		
		(CC60)	= 0	
7	-	Flight Condition card — Type 9		
		LAST	= 0	Program will expect a new Element Data Title card after forces are calculated.
		Number α-β	= 5	5 angles of attack are to be used.
		Use Old α-β	= 0	Flight-attitude cards are input.
		NO.S.F.	= 0	No skin-friction cards for this component.
8	-	Center-of-Gravity card — Type 10		
9	-	Flight Attitude Data cards — Type 12		
		5 cards, one for each angle of attack		
10	-	Element Data Title card for component number two.		
		ISUM	= 1	Save force contribution for future summation.

Card				
11	- Element Data Control card — Type 2			
	IGEOM	=	0	Element data is input.
	ITAPE	=	4	Read geometry data from normal input Tape 5 and also write these same data on Tape 8 for use along with the ellipse data by the picture drawing program.
	IGTYPE	=	0	Not a control-surface flap
	IELOV	=	0	Calculate quadrilaterals
12	- Element Data Geometry cards — Type 3			
	Use as many Type 3 cards as required to describe the shape. Last card has STATUS = 3.			
13	- Force Data Title card — Type 8			
	Return to Type 1	=	0	
14	- Flight-Condition card — Type 10			
	LAST	=	0	Program will expect a new Element Data Title card after forces are calculated.
	Number α-β	=	5	5 angles of attack are to be used.
	Use old α-β	=	0	Flight Condition cards are included.
	NO.S.F.	=	0	No skin-friction cards for this component.
15	- Center-of-Gravity card — Type 10			
16	- Flight-Attitude Data cards — Type 12			
	5 cards, one for each angle of attack			
17	- Element Data Title card to sum up the data for the two components — Type 1			
	ISUM	=	2	Print summation of forces for both components.
18	- Element Data Title card — Type 1 (For skin-friction calculations).			
	ISUM	=	1	Save resulting force data for summation.
19	- Element Data Control card — Type 2			
	IGEOM	=	0	Element data are input.
	ITAPE	=	0	Geometry data input on normal input Tape 5.
	IELOV	=	0	Calculate quadrilaterals
	IGTYPE	=	2	Skin-friction geometry is input.

Card

20 - Element Data cards - Type 3. Skin-friction geometry is input using the regular element input method. Use as many elements as are required to give a good approximation of the vehicle shape (approximate areas of large curvature with several flap plate elements). Each input surface element will probably be a separate section (four data points with the first having a STATUS of 2, using two Type 3 cards per element), with the last point of the last element having a STATUS of 3 (dummy elements to give a STATUS of 3 are not permitted in the skin-friction geometry deck).

21 - Force Data Title card – Type 8

Return to Type 1	=	0	

22 - Flight Condition card – Type 9

LAST	=	0	Data Title card after forces are calculated.
Number α-β	=	5	5 angles of attack are to be used.
Use old α-β	=	1	No Type 12 cards are included. Use previous component Type 12 card data for pressure calculations on the skin-friction elements.

No. of skin-friction elements = number of elements input

23 - Center-of-Gravity card – Type 10

24 - Skin Friction Cards – Type 11

One Type 11 skin-friction card for each element

25 - Element Data Title card to sum up the data for both components and the skin-friction contribution – Type 1.

ISUM	=	2	Print summation of all data on summation tape.

26 - Phase Termination card – Type = 99

27 - Element Data Title card for pictures – Type 31

28 - Element Data Control card – Type 32

Use Scale Factors	=	1	Use scale factors to shift coordinate center to center of vehicle to simplify picture scale selection.
XSCALE	=	1.0	
YSCALE	=	1.0	
ZSCALE	=	1.0	
AXSCALE	=		A value equal to about one-half of the vehicle length.

Card				
28		Number of Status 3	= 2	This vehicle contains 2 STATUS = 3.
		ITAPE	= 1	Geometry data will be read from Tape 8 as prepared by the AERO option.
		IREW8	= 0	Rewind Tape 8 before reading geometry data
29	-	Viewing Angle Data card — Type 34		
		LAST	= 0	Not the last picture.
30	-	Scale Data card — Type 35		
		No Scale	= 1	Do not draw scales.
31	-	Plot Title card — Type 37		
32	-	Viewing Angle Data card — Type 34		
		LAST	= 1	This is the last picture.
33	-	Scale Data Card — Type 35		
34	-	Plot Title card — Type 37		
35	-	Phase Termination card — Type 99		

The previous two sample problems are typical applications of this analysis system. One example was very simple and the other somewhat more complicated. These two samples illustrate both the flexibility of the analysis system and the care that must be used in preparing the input data. The user should remember that every key control flag must have the proper value for the problem to run successfully.

INPUT CHECK LIST

The last step in preparing input for this program is to check that all the cards are in the proper order, that each card has the correct type number, and that all the key program flags have been properly set. A machine listing of the input cards is very helpful in performing this check. It is easier to detect errors on such a listing than it is to find errors on the load sheet or on the cards themselves. Each item on the check list below should be reviewed before a deck of cards are submitted to the program.

General Items

1. Check phase option selections.
2. Check last card of each phase — it should be a Type 99 card.

3. Check card order by reviewing card type numbers. Every card must have a valid type number.

4. Check all key control flags that involve the determination of card order.

5. Check accuracy of all numerical data.

6. Check that the last geometry-data surface point for each component has STATUS = 3.

7. Check the proper positioning of Tape 8 for each part of the problem.

8. If the shock-expansion pressure method is to be used, check that the geometry orientation flag (IORIEN) has been properly set. Also check that the leading elements for the shock-expansion process have the proper geometric position.

9. If a control-surface problem is to be solved, check that the fore-surface and control flap have been loaded as one component (two sections, with the fore-surface first). The elements must be oriented strip-wise (IORIEN $\geq$ 1) with the same number of stream-wise strips in both the fore-surface and flap. Maximum number of elements in a stream-wise strip (including both fore-surface and flap) should not be greater than 125.

10. If free-molecular-flow force method has been selected, check if the whole vehicle has been loaded (top, bottom, sides, base, etc.), and that the free-molecular-flow option has been selected for both impact and shadow regions.

11. If geometry data cards are to be punched from Tape 8, do not rewind the tape at the end of last phase but leave it in its last geometry data position. The FORTRAN system will then write an end-of-file behind the data and rewind the tape for removal and punching.

Key Input Items

Card Type	Card Name	Key Card Columns
1	Element Data Title Card	60, 61
2	Element Data Control Card	3, 5, 60, 61, 62, 63
3	Element Data	31, 62 (last point in component must have STATUS = 3).
4	Ellipse Generation Data	60
5	X-Station Card	60
6	Parametric Cubic Title Card	60
7	Parametric Cubic Boundry Data	31, 62 (last point in each patch must have STATUS = 3).
8	Force Data Title Card	60
9	Flight Condition Card	60, 61-62, 63, 64-65

Card Type	Card Name	Key Card Columns
10	Center of Gravity Card	1-10 (usually negative)
11	Skin Friction Data	11-19 (wetted area in same units as SREF).
12	Flight Attitude Data	41-42, 43-44
13	Coefficient Increment Data	Same number of cards as α-β cards when ITYP13 = 1.
14		
15		
16		
17		
18		
19		
20		
21		
22	Thrust Vector Data	60 (N_x, N_y, N_z must be direction cosines of force vector. At least one vector card must be present for each angle of attack when IVECT = 1).
31	Element Data Title Card	
32	Element Data Control Card	3, 5, 60-61, 62, 63
34	Viewing Angles	60
35	Scales	60
36	Labels	
37	Plot Titles	
41	Data Source Control	4
44	Vertical Title	
45	Horizontal Title	
46	Plotting Grid	
47	Plotting Array	
48	Horizontal Label Cards	

SECTION IV

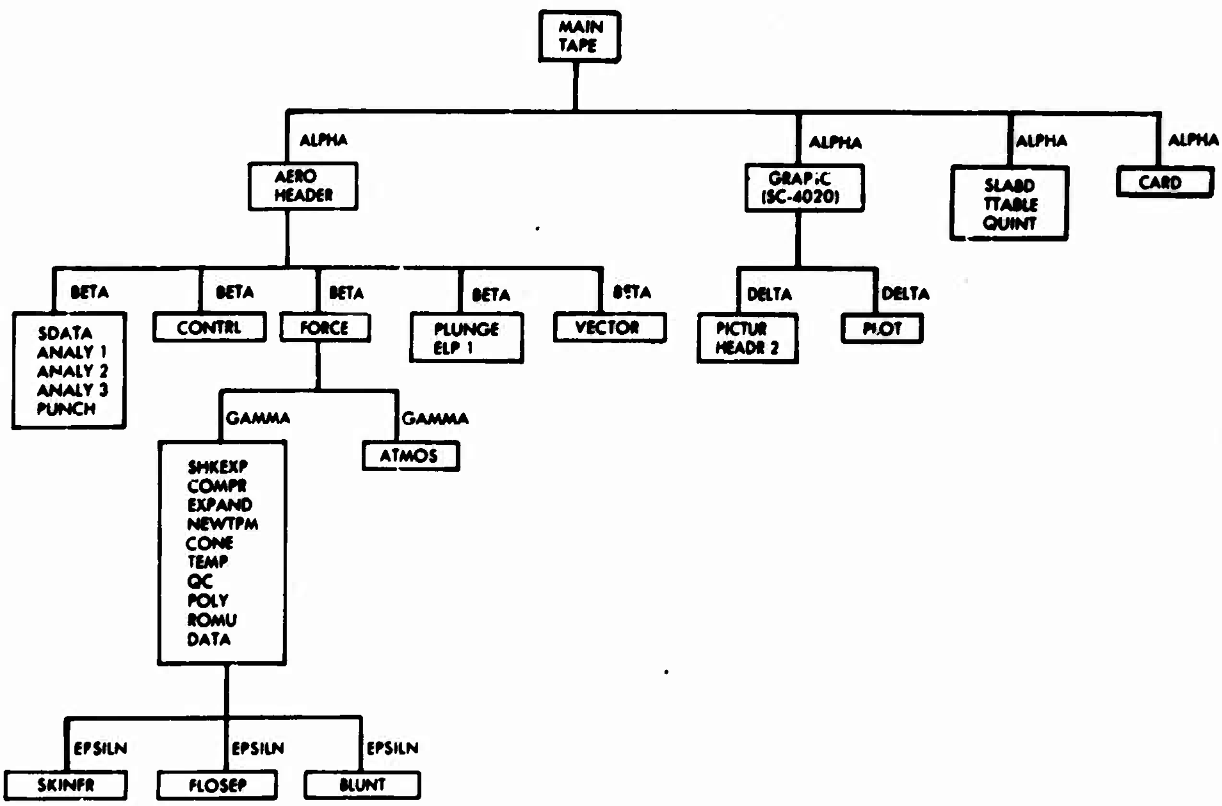
OPERATIONAL CONSIDERATIONS

The Mark III version of the Hypersonic Arbitrary-Body Aerodynamic Computer Program is written entirely in FORTRAN. Models of the Mark III program are available for use on the IBM 360, the IBM 7094, and the UNIVAC 1108 computers. For the Mark III program the IBM 360 model is considered to be the base-line program. The differences between the programs are of a minor nature and modifications necessary for operation on other similar computers should be easy to accomplish. The program also makes use of the Douglas version of the SC-4020 software system package to generate a plotting tape. This tape is then processed off-line by a Stromberg Carlson SC-4020 Data Recording System. The graphics parts of the program may be converted by the user for operation with on-line graphics equipment such as the IBM 2250.

OVERLAY STRUCTURE

Because of the large size of this program it is necessary to use the overlay feature of FORTRAN to permit operation on most computer systems. The overlay structure to obtain the minimum size program is shown in the chart below. At the Douglas computer complex this permits the operation on the IBM 360/65 (total program length of approximately 105,000 bytes) and the IBM 7094 (32K machine).

OVERLAY STRUCTURE
MARK III PROGRAM



Additional information concerning deck set-up and operation, tape assignments, etc., is presented in Section IV of Volume II of this report.

SECTION V

OUTPUT DATA

The amount of output data generated by this program is controlled by the various input print flags. The basic philosophy involved in the output-data printing is outlined below.

The force characteristics at each vehicle angle of attack are not printed as they are calculated but are saved for printing after all angles of attack have been evaluated. This facilitates both the normal printing of data (i. e., the most important summary force data) and the saving of data for summation and possible plotting by the automatic plotter.

Sample output summary force data are shown on page 133. The force-data output sheet is divided into two sections, with the force characteristics on the left and the force-method control data on the right. The basic output data consist of a two-line block of data for each angle-of-attack–yaw-angle combination. If derivatives are calculated then additional lines will be printed containing these data. The conventional aerodynamic-force-coefficient and derivative symbols corresponding to the program-printed mnemonics are presented on page 135.

The coordinate system sign convention used for the geometry data input to this program is shown in the figure on page 86. This sign convention is not consistent with usual stability and control practices. However, it should be noted that the sign conventions used in the printout of the program coefficients and stability derivatives have been corrected for this difference so as to be consistent with standard practice. The one exception to this is the control surface deflection derivative sign convention. Because of the complete generality provided in the program for the positioning of control surfaces it became necessary to adapt a simple rule for all conditions — a positive control deflection is a deflection outward into the flow. The sign conventions used for the other vehicle coefficients are shown on page 135.

When the program starts to print the data header information at the top of the force-data output it checks to see what derivatives have been calculated. If derivative data are calculated at any angle of attack the appropriate header line will be printed. For each angle of attack a line of output data will be printed to correspond to each header line. If at a particular angle of attack no derivatives had been calculated the program will still print a full output line to match the header (if no values had been calculated the program will print 0.00000).

As the program proceeds through each phase of its calculations certain data are generated that, at times, would be useful output data. Data in this category include detailed element characteristics and force contributions of each individual element. This type of data is not printed unless the proper print flag has been set.

Sample sheets for various other optional output data are shown on page 134. These include a detailed printout of the input element characteristics, and

the detailed force contributions of each surface element (used only when detailed pressure distributions are required). Also shown is the normal skin-friction output data format. The symbols used in the skin-friction printout are described in detail on pages 140 through 142.

A sample printout of the geometric properties of a quadrilateral element is shown at the top of page 134. This printout for each vehicle element may be obtained by inputting PRINTS = 1 on the Element Data Title Card. The printed data obtained include the unit-normal direction cosines, the quadrilateral centroid, area, and volume contribution, and the X-Y-Z coordinates of the corner points of the input surface element (in a clockwise order around the element). This printout option will result in a large amount of output if the number of elements is high. The area values and volume contributions printed out are for the input geometry data and do not include symmetry aspects.

The second sample printout on page 134 is an example of the detailed force-contribution results that may be obtained by setting PRINT = 1 on the Flight Attitude Data Card. This print option can also generate a large amount of printout. When the shock-expansion pressure method is used, additional local flow information may be obtained by IPRINT = 1 on the Flight Attitude Data Card.

The skin-friction data shown in the last example on page 134 may be obtained by setting all of the skin-friction print flags ($IS_{I,7}$, $IS_{I,8}$, and $IS_{I,9}$) equal to one. In this example the Force data print flag was also turned on. For skin-friction calculations it is advisable that $IS_{I,7}$, and $IS_{I,8}$ be turned on for all cases and that $IS_{I,8}$ be set equal to two. A large amount of output is not produced and the information is usually found to be useful.

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   10                                                                                         PAGE   10

SAMPLE OUTPUT WITHOUT DERIVATIVES

  MACH=  18.000  VEL=  19911.4 FT/SEC  RE/FT =  0.31018E 05
  ALT = 200000.

  S REF =   128.25  SPAN =    5.70  MAC  =   30.00
  X CG  =   -15.00  Y CG =    0.00  Z CG =    0.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N         K                   IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF               ISHAD   ENPM   ISHADI

   0.00   0.00957   0.00040   0.00997   0.00000   0.00000   2.00000                  9    1.0000    5      0.00
   0.00   0.04201   0.00000   0.00000   0.00000   0.00057   1.00000                  2    1.0000    3
```

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   10                                                                                         PAGE  198

SAMPLE OUTPUT WITH ALPHA DERIVATIVES AND WIND TUNNEL CONDITIONS

  MACH=   8.080  VEL=   4724.1 FT/SEC  RE/FT =  0.21082E 07
                 P STAG=  61.3 ATMOS   T STAG= 1540.0 DEG F

  S REF =    41.62  SPAN =    7.28  MAC  =   10.00
  X CG  =   -10.00  Y CG =    0.00  Z CG =    0.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N         K                   IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF               ISHAD   ENPM   ISHADI
            CA A      CL A      CN A      CM A
            CM Q      CA Q      CN Q      CMA D                                      Q

   0.00   0.23327   0.00000   0.23327   0.00000   0.00000   2.00000                  1    1.0000    0      0.00
   0.00   0.00000   0.00000   0.00000   0.00000   0.00000   1.00000                  1    1.0000    0
          0.00020   0.02670   0.03078   0.00755
          0.45920   0.00011  -0.86507   0.00000                                    0.0
```

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   10                                                                                         PAGE  159

SAMPLE OUTPUT WITH BETA DERIVATIVES

  MACH=   8.080  VEL=   4724.1 FT/SEC  RE/FT =  0.21082E 07
                 P STAG=  61.3 ATMOS   T STAG= 1540.0 DEG F

  S REF =    41.62  SPAN =    7.28  MAC  =   10.00
  X CG  =   -10.00  Y CG =    0.00  Z CG =    0.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N         K                   IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF               ISHAD   ENPM   ISHADI
            CY B      CLN B     CLL B
            CY R      CLN R     CLL R     CYB D                                      R

   0.00   0.23406   0.00000   0.23406  -0.04153   0.00000   2.00000                  1   -0.0000    0      0.00
   2.00   0.00000   0.00000   0.00000  -0.02073   0.00000   1.00000                  1    0.0000    0
         -0.03070  -0.01033   0.00000
         -0.86641  -0.83106  -0.00001  -0.00000                                    0.0
```

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE  930                                                                                         PAGE   46

SAMPLE OUTPUT WITH CONTROL SURFACE DERIVATIVES

  MACH=  20.000  VEL=  21568.4 FT/SEC  RE/FT =  0.80656E 05
  ALT = 175000.

  S REF =  1091.80  SPAN =   34.90  MAC  =   50.00
  X CG  =   -27.50  Y CG =    0.00  Z CG =    0.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N         K                   IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF               ISHAD   ENPM   ISHADI
            CM D      CLL D     CY D      CLN D     CN D                             HM L     HM R

  25.00   0.06669   0.10093   0.01779   0.00000   0.11966   2.01500                  1    0.0000    3     15.00
   0.00   1.51345  -0.04070   0.00000   0.00000   0.00000   1.00000                  1    0.0000    3
        -1.98E-03   0.        0.0       0.0     4.24E-03                           -3.03E 04  0.0
```

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   10                                                                                PAGE    1

SAMPLE OUTPUT OF CHARACTERISTICS OF INPUT ELEMENT DATA

  INPUT SURFACE ELEMENT DATA

     N   M        X              X              X              X            NX          XCENT         AREA         L
                  Y              Y              Y              Y            NY          YCENT        DELTA V
                  Z              Z              Z              Z            NZ          ZCENT        VOLUME


     1   1  -3.00000E 00   -3.00000E 00   -8.00000E 00   -8.00000E 00   0.048540   -6.33333E 00   3.82915E 00     1
             0.0            0.0            1.53000E 00    0.0            0.0        5.10000E-01    0.0
             2.02950E 01    2.02950E 01    2.00620E 01    2.00620E 01 -0.998816   2.01397E 01    0.0



HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE  930                                                                                PAGE   45

SAMPLE OUTPUT FOR DETAILED ELEMENT FORCE CONTRIBUTIONS (INCLUDING CONTROL SURFACE DATA)

ELEMENT DATA   MACH= 20.000  ALT = 175000.  S REF =  1C91.0  SPAN =   34.9  IMPACT =  1  IMPACI =  3
               XCG =  -27.5  YCG =    0.0   ZCG  =    0.0    MAC =   50.0 * ISHAD =  1  ISHADI =  3
    ANGLE OF ATTACK = 25.00    YAW ANGLE = -0.00   K = 2.01500   ETAC =  0.0      DELTA E = 15.00
    IDERIV =  4   Q = 0.0            R = 0.0            P = 0.0

  L      DEL CA        DEL CY         DEL CN        DEL CLL        DEL CLM        DEL CLN        CP            AREA
           CA            CY             CN            CLL            CLM            CLN         DELTA

  81   0.44251E-03   0.0            0.16515E-02   0.0           -0.76474E-03   0.0            0.12310E 01   0.75818E 00
       0.16459E-01   0.0            0.11471E 00   0.0           -0.38355E-01   0.0            0.25000E 02
       DELTA CP CONTROL = 0.87113E 00  FORCE METHOD CP = 0.35989E 00  H.M. (+Y) =-0.26316E 05  H.M. (-Y) = 0.0



HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  SKIN FRICTION SAMPLE OUTPUT WITH ALL PRINT FLAGS TURNED ON                               PAGE    5

SKIN FRICTION METHODS CHECKOUT

 FREE STREAM CONDITIONS
        ALPHA =   0.0        MACH    = 19.08   VELOCITY =  20000.4   ALTITUDE = 200000.0
        RE/FT = 3.116E 04    S REF   =       1.0

  KT =    1     TC1 = 0.100000E 03     TR1 = 0.100000E 03     TC2 = 0.973633E 03     TR2 = 0.973633E 03
  ITW=    1     QC1 = 0.268468E 03     QR1 = 0.298752E-01     QC2 = 0.254903E 03     QR2 = 0.268468E 03
  KT =    2     TC1 = 0.931608E 03     TR1 = 0.931608E 03     TC2 = 0.961688E 03     TR2 = 0.961688E 03
  ITW=    1     QC1 = 0.255535E 03     QR1 = 0.225032E 03     QC2 = 0.255082E 03     QR2 = 0.255535E 03

  NW= 6    IDEAL GAS, REF. T/REF. T  SOLUTION.
  KT= 2    THEQ =   961.2R   CF1 = 0.232779E-03   CF1(RE1) = 0.410888    ROMURA =  0.38292   H*/H1 =  13.1519   HAW/H1 =  62.3822

  KT =    1     TC1 = 0.100000E 03     TR1 = 0.100000E 03     TC2 = 0.118536E 04     TR2 = 0.118536E 04
  ITW=    1     QC1 = 0.589809E 03     QR1 = 0.298752E-01     QC2 = 0.531154F 03     QR2 = 0.589809E 03
  KT =    2     TC1 = 0.108718E 04     TR1 = 0.108718E 04     TC2 = 0.115739E 04     TR2 = 0.115739E 04
  ITW=    1     QC1 = 0.536081E 03     QR1 = 0.417366E 03     QC2 = 0.532551E 03     QR2 = 0.536081E 03

  NW= 6    IDEAL GAS, REF. T/REF. T  SOLUTION.
  KT= 2    THEQ = 1155.5R   CF1 = 0.461695E-03   CF1(RE1) = 0.009185    ROMURA =  0.07104   H*/H1 =  14.0756   HAW/H1 =  65.9879

 SKIN FRICTION DATA
        SURF NO.    TYPE      METHOD      S WET     LENGTH    ALPHA D     WEDGE      ANGLE(2)  RE LOC      CHI BAR   V BAR
  LAM      CF        CA         CN       SUM CA     SUM CN      TW         TW/T       TW/TR    RE*/FT        CD     CF/CFO
  TURB     CF        CA         CN       SUM CA     SUM CN      TW         TW/T       TW/TR    RE*/FT        CD     CF/CFO
          MACH        V       V SOUND    P-PSF      TEMP-R   RHO*10**4  VIS*10**7     RE/FT   C STAR        C      V STAR


           7          0         2           1.     100.0       0.0        0.0         0.0   3.116E 06     3.566  0.0098
  LAM    0.00083   0.0        0.0        0.0        0.0        961.2      2.1034      0.0337 4.704E 02   0.0       1.7901
  TURB   0.00064   0.0        0.0        0.0        0.0       1155.5      2.5286      0.0383 4.240E 02   0.0       1.0000
  STREAM 19.08499  20000.4   1047.97     0.4134     456.99 0.0052696   3.382647 3.116E 04 3.826E-01 8.149E-01 0.0067
  LOCAL  19.08499  20000.4   1047.97     0.4134     456.99 0.0052696   3.382647 3.116E 04

ELEMENT DATA   MACH= 19.085  ALT = 200000.  S REF =      1.0  SPAN =      1.0  IMPACT =  1  IMPACI =  0
               XCG =   -0.5  YCG =    0.0   ZCG  =    0.0    MAC =      1.0   ISHAD =  1  ISHADI =  0
    ANGLE OF ATTACK =  0.0    YAW ANGLE =  0.0    K = 2.00000   ETAC =  1.0000   DELTA E =  0.0
    IDERIV =  0   Q = 0.0            R = 0.0            P = 0.0

  L      DEL CA        DEL CY         DEL CN        DEL CLL        DEL CLM        DEL CLN        CP            AREA
           CA            CY             CN            CLL            CLM            CLN         DELTA

  7    0.12785E-02   0.0            0.0           0.0            0.0            0.0            0.0           0.10000E 01
       0.71154E-02   0.0            0.0           0.0            0.0            0.0            0.0
```

OUTPUT DATA SYMBOLS

SUMMARY FORCE DATA

Basic Data

ALPHA	Angle of attack degrees	
BETA	Yaw angle, degrees (positive with the wind striking the right side of the vehicle).	
C D	C_D	drag coefficient
C L	C_L	lift coefficient
C A	C_A	axial force coefficient
C Y	C_Y	side force coefficient (positive when force is pushing on left side of vehicle toward the right).
C N	C_N	normal force coefficient
K	K	Newtonian correlation factor
L/D	L/D	lift-to-drag ratio
C M	C_m	pitching moment about component or vehicle center of gravity (based on vehicle length parameter, MAC).
C LL	C_ℓ	rolling moment coefficient based on reference length, SPAN (positive when tending to cause a roll to the right).
C LN	C_n	yawing moment coefficient based on reference length, SPAN (positive when tending to force the nose to the right).
C F	C_f	axial force contribution caused by skin friction (not used in Mark III Mod 0 version of program)
Q/Q INF	Q/Q_∞	local pressure coefficient correction factor

Derivative Data In Pitch. (At specified angle of attack, yaw angle, and pitch rate).

CA A	C_{A_α}	derivative of axial force with respect to angle of attack (per degree).
CL A	C_{L_α}	derivative of lift coefficient with respect to angle of attack (per degree).
CN A	C_{N_α}	derivative of normal force coefficient with respect to angle of attack (per degree).
CM A	C_{m_α}	derivative of pitching moment coefficient with respect to angle of attack (per degree).
CM Q	C_{m_q}	pitching moment dynamic stability derivative due to pitching velocity (at the input value of Q).

$$C_{m_q} = \frac{\partial C_m}{\partial\left(\frac{q\,MAC}{2V}\right)}$$

CA Q	C_{A_q}	axial force derivative due to pitching velocity.
CN Q	C_{N_q}	normal force derivative due to pitching velocity.
CMA D	$C_{m_{\dot\alpha}}$	dynamic stability in pitch due to vertical acceleration.

$$C_{m_{\dot\alpha}} = \frac{\partial C_m}{\partial\left(\frac{\dot\alpha MAC}{2V}\right)}$$

Derivative Data In Yaw (At specified angle of attack, sideslip angle and yaw rate.)

CY B	C_{Y_β}	side force derivative due to sideslip (per degree).
CLN B	C_{n_β}	yawing moment derivative due to sideslip angle.
CLL B	C_{ℓ_β}	rolling moment derivative due to sideslip angle.

CY R	C_{Y_r}	side force dynamic stability derivative due to yawing velocity

$$C_{Y_r} = \frac{\partial C_Y}{\partial\left(\frac{r\,SPAN}{2V}\right)}$$

CLN R	C_{n_r}	yawing moment dynamic derivative due to yawing velocity

$$C_{n_r} = \frac{\partial C_n}{\partial\left(\frac{r\,SPAN}{2V}\right)}$$

CLL R	C_{ℓ_r}	rolling moment dynamic derivative due to yawing velocity

$$C_{\ell_r} = \frac{\partial C_\ell}{\partial\left(\frac{r\,SPAN}{2V}\right)}$$

CYB D	$C_{Y_{\dot\beta}}$	side force derivative due to horizontal acceleration

$$C_{Y_{\dot\beta}} = \frac{\partial C_Y}{\partial\left(\frac{\dot\beta MAC}{2V}\right)}$$

Control Surface Derivatives (at specified control surface deflection)

CM D	C_{m_δ}	pitching moment derivative with respect to control surface deflection per degree. Note that control surface deflections are positive when deflected outward into the flow.
CLL D	C_{ℓ_δ}	rolling moment derivative due to control surface deflection.
CY D	C_{Y_δ}	side force derivative due to control surface deflection.

CLN D	C_{n_δ}	yawing movement derivative due to control surface deflection
CN D	C_{N_δ}	normal force derivative with respect to control surface deflection

Control Data

IMPACT		impact pressure method
ISHAD		shadow region pressure method
ETAC	η_c	Prandtl-Meyer modification factor (see Newtonian + Prandtl-Meyer pressure method)
ENPM	θ/θ_{Body}	body slope modification factor (see CC 31-35 of Flight Attitude Data Card)
IMPACI		leading element impact pressure method for shock-expansion calculations (see CC 49-50 of Flight Attitude Data Card)
ISHADI		leading element shadow pressure method for shock-expansion calculations (see CC 51-52 of Flight Attitude Data Card)
DELTA E	δ_e	control surface deflection (positive when deflected outward into the flow)
Q	q	pitch rate, rad/sec.
R	r	yaw rate, rad/sec.
HM L		hinge moment in foot - pounds for + Y (input side of vehicle
HM R		hinge moment in foot - pounds for - Y (reflected side of vehicle if vehicle is yawed or yawing)

INPUT SURFACE ELEMENT DATA

N	element column number
M	element row number
L	element number
X, Y, Z	coordinates of input surface element corner points (given clockwise around the element)
NX, NY, NZ	direction cosines of outward surface normal

X CENT Y CENT Z CENT		centroid of quadrilateral
AREA		quadrilateral surface area
DELTA V		volume contribution of element when projected on to the X-Z plane (= NY · YCENT · AREA)
VOLUME		summation of element volume contributions

DETAILED FORCE CONTRIBUTIONS

IDERIV		input derivative flag
L		element number
DEL CA	ΔC_A	axial force increment for element
CA	C_A	summation of axial force increments
DEL CY	ΔC_Y	side force increment
CY	C_Y	summation of side force increments
DEL CN	ΔC_N	normal force increment
CN	C_N	summation of normal force increments
DEL CLL	ΔC_ℓ	rolling moment increment
CLL	C_ℓ	summation of rolling moment increments
DEL CLM	ΔC_m	pitching moment increment
CLM	C_m	summation of pitching moment increments
CLN	C_n	summation of yawing moment increments
CP	C_p	element pressure coefficient
DELTA	δ	element impact angle, degrees
AREA		element area (input element only)

SKIN FRICTION DATA

SURF NO.		skin-friction surface number (1 to 10)
TYPE		surface type (= 0 flat plate, use oblique-shock) (= 1 use tangent-cone rather than oblique-shock)
METHOD		compression and expansion surface pressure method (see page 68)
S WET		wetted area of skin-friction surface (note that areas input or calculated with values less than 1.0 will print as 0)
LENGTH		input length of skin-friction surface -feet
ALPHA 0		input longest length of the initial-surface (Mode 1) input surface angle (α_i) for Mode 2 operation
WEDGE		input taper-ratio of the initial-surface (Mode 1) input wedge angle (α_W) for Mode 2 operation
ANGLE(2)		absolute value of flow turning angle, degrees
RE LOC	Re_x	local Reynolds number
CHI BAR	$\bar{\chi}$	hypersonic interaction parameter based on surface conditions $\bar{\chi} = M_\infty^3 \sqrt{C/Re_x}$
V BAR	$\bar{V}_\infty$	hypersonic viscous parameter (includes plan-form effects) $\bar{V}_\infty = M_\infty \sqrt{C/Re_x}$
CF	C_F	final average skin-friction coefficient based on free-stream conditions (includes viscous-inviscid interaction in laminar results)
CA	C_A	skin-friction contribution to axial force (only used for Mode 2 operation)
CN	C_N	skin-friction contribution to normal force (only used for Mode 2 operation)
SUM CA	ΣC_A	summation of surface axial force contributions (only used for Mode 2 operation)
SUM CN	ΣC_N	summation of surface normal force contribution (only used for Mode 2 operation)
TW	T_W	surface temperature, $^o R$
TW/ T	T_W/T_∞	wall to free-stream temperature ratio
TW/TR	T_W/T_R	wall to recovery temperature ratio
RE*/FT		Reynolds number based on reference conditions

SKIN FRICTION DATA (Continued)

CD	C_D	drag coefficient contribution (used in Mode 2 only)
CF/CFO	C_f/C_{f_o}	ratio of skin friction with viscous-inviscid interaction to skin friction without interaction
MACH	M	Mach number
V	V	velocity, feet/second
V SOUND		speed of sound, feet/second
P-PSF		pressure, lb/ft^2
TEMP-R		temperature, ^oR
RHO*10**4		density times 10^4
VIS*10**7		viscosity times 10^7
RE/FT		Reynolds number per foot
C STAR	C_∞^*	Chapman-Rubesin viscosity coefficient evaluated at reference conditions $C_\infty^* = (\mu^*/\mu_\infty)(T_\infty/T^*)$
C	C	Chapman-Rubesin viscosity coefficient evaluated at wall conditions $C = (\mu_W/\mu_\infty)(T_\infty/T_W)$
V STAR	$\bar{V}_\infty^*$	hypersonic viscous parameter evaluated at reference conditions $\bar{V}_\infty^* = M_\infty \sqrt{C^*/Re_x}$
NW		wall temperature and skin-friction calculation flag (input as $IS_{I,6}$ in CC 7 on Type 11 card)
KT		number of iterations required in calculating the equilibrium wall temperature (if =11 something is wrong)
TWEQ	T_W	equilibrium (or input) wall temperature, ^oR
CF1	C_f	local skin-friction coefficient based on free-stream conditions
CF1(RE1)	$C_f(Re_x)^{1/N}$	normalized skin-friction parameter (for laminar flow N = 2, for turbulent flow N = 5)
ROMURA		laminar flow - ratio of reference density-viscosity product to free-stream density-viscosity product $(\rho^*\mu^*/\rho_\infty\mu_\infty)$ turbulent flow - the ratio one over the compressibility factor (1.0/FC)
$H^*/H1$	H^*/H_∞	ratio of reference condition enthalpy to free-stream enthalpy
HAW/H1	H_{AW}/H_∞	ratio of adiabatic wall enthalpy to free-stream enthalpy

SKIN FRICTION DATA (Continued)

ITW	type of temperature iteration, = 1 for ideal gas, and = 2 for real gas
TC1	first value of temperature at which convective heating is calculated, ^oR
TC2	second value of temperature at which convective heating is calculated, ^oR
TR1	first value of temperature at which radiation heating is calculated, ^oR
TR2	second value of temperature at which radiation heating is calculated, ^oR
QC1	convective heating rate at TC1, (BTU/ft^2sec)
QC2	convective heating rate at TC2, (BTU/ft^2sec)
QR1	radiation heating rate at TR1, (BTU/ft^2sec)
QR2	radiation heating rate at TR2, (BTU/ft^2sec)

SECTION VI

ERROR MESSAGES

Each part of the Hypersonic Arbitrary-Body Program contains special check statements. These program instructions are designed to detect when the program will get into computational difficulty, either because of some input data error, or because of some internal program difficulty that would lead to erroneous data. The next page contains a list of the program error notes that are printed when these check statements are encountered. The subroutine where the statement is printed is also given.

The most frequent type of input data error is caused by a failure to provide proper data card order. This type of error can be avoided by frequent reference to the input data charts provided in Appendix C. A check of the input data by using a machine listing of all the input cards will also help prevent card type errors.

Input data card order errors may be detected in two different places. First, if a program READ statement expects only numerical data, and instead gets alphabetic information, then the FORTRAN system will stop the program. An error trace will be printed and should, with the use of a program listing, lead the user to that part in the program where the error occurred.

Second, if the FORTRAN system accepts an input card that has a card type number not expected by the program, then the program itself will print an error note. In most of these types of errors the program will flush the remainder of the data cards until it finds a Type 99 phase termination card. The program will print an appropriate note and then attempt to continue with the next phase of the problem.

PROGRAM ERROR NOTES	SUBROUTINE
A NON-FATAL ERROR OCCURRED IN PHASE XX. PROGRAM WILL ATTEMPT TO CONTINUE BY SEARCHING FOR NEXT TYPE = 99 CARD.	MAIN
**** BASIC INPUT FLAG ERRORS - SUBROUTINE PLUNGE IPART AND ICALC ARE XXXX XXXX **** TO ERR IS HUMAN	PLUNGE
*** CONGRATULATIONS - YOU HAVE HIT THE JACKPOT WITH AN ERROR INVOLVING EITHER CARD ORDER OR CARD TYPE INDICATION*** THE CARD LOCATED JUST BEFORE THE CARD LISTED BELOW IS IN ERROR	AERO
****DURING SHOCK-EXPANSION CALCULATIONS PROGRAM TRIED TO USE WRONG INITIAL ELEMENT METHOD--CHECK INPUT****	SHKEXP
***** ELEMENT DATA CONTROL CARD IS NOT PRESENT OR HAS THE WRONG TYPE NUMBER *****	SDATA
**** ELLIPTICAL INTEGRAL ERROR. T1 FROM PLUNGE IS NOT LESS THAN ONE AND GREATER THAN OR EQUAL TO ZERO	PLUNGE
***** FIRST PHASE OPTION IS ZERO ********* FATAL ERROR ****	MAIN
FOR SOME ODD REASON, TYPE CARD XX DOES NOT HAVE A XX IN COLUMN 71-72. BETTER LUCK NEXT TIME. WRITTEN BELOW IS THE IMAGE OF THE CARD FOLLOWING THE INCORRECT ONE	PLOT
***** FORCE ROUTINE WILL ATTEMPT TO FIND THE ARCCOSINE OF AN ARGUMENT WHOSE ABSOLUTE VALUE IS GREATER THAN ONE ***** *** JOB WILL BE TERMINATED ***	FORCE
**** INPUT MACH NUMBER IS NOT SUPERSONIC. SKIN FRICTION ANALYSIS FOR THIS POINT IS STOPPED ****	SKINFR
***** MASTER CONTROL CARD HAD TYPE NOT = 0 ******	MAIN
NO MORE SC-4020 DATA IS PLOTTED BECAUSE OF AN ERROR IN YOUR INPUT CARDS	PICTUR
***** NUMBER OF ALPHA-BETA CONDITIONS CANNOT BE GREATER THAN 20. JOB WILL BE ATTEMPTED WITH NAB = 20 *****	AERO
****NUMBER OF INITIAL ELEMENT CANNOT EXCEED 100 FOR SHOCK-EXPANSION CALCULATIONS. CHANGE INPUT DATA****	SHKEXP
**** NUMBER OF STREAMWISE ELEMENTS FOR CONTROL FORE-SURFACE AND FLAP CANNOT EXCEED 125 ****	FLOSEP
***** NUMBER OF STREAMWISE STRIPS ON FORE-SURFACE AND FLAP MUST BE THE SAME. CHANGE GEOMETRY DATA *****	SDATA
**** ON CONTROL SURFACE, ORIENTATION WAS INPUT AS = 0 PROGRAM CONTINUED WITH ORIENTATION SET = 1 ****	SDATA
***** PROGRAM HAS ATTEMPTED TO READ A ALPHA-BETA COMBINATION CARD WITH THE WRONG TYPE CODE*****	AERO
***** PROGRAM OPTION IS GREATER THAN 4 ******** FATAL ERROR ****	MAIN
***ROLL DERIVATIVE PART OF PROGRAM IS NOT OPERATIVE AT THE PRESENT TIME	AERO
**** SUBROUTINE PLUNGE SETS ERROR FLAG	PLUNGE
**** SUBROUTINE PLUNGE - THE FLAG ITYPE (WHICH CONTROLS EQUATION USED TO CALCULATE KBW) IS INCORRECT AND = XXXXX	PLUNGE
***** SURFACE DATA ROUTINE HAS ATTEMPTED TO READ A NON-SURFACE CARD - CHECK YOUR CARDS *****	SDATA
THE FOLLOWING CARD ON TAPE 8 IS IN ERROR	PICTUR
***** TOTAL NUMBER OF ELEMENTS ON CONTROL SURFACE CANNOT EXCEED 300 ***	CONTRL
*****YOU HAVE MADE AN ERROR EITHER IN CARD TYPE INDICATION OR CARD ORDER - CHECK YOUR CARDS***** THE CARD LOCATED JUST BEFORE THE CARD LISTED BELOW IS IN ERROR	PICTUR

SECTION VII

PROGRAM LIMITATIONS AND RESTRICTIONS

The degree of development of any computer program depends upon a number of factors. The limitations imposed by computer size and speed, the time and manpower available for formulation and programming, the general state of the art in the technical discipline - all influence to a large extent the capability provided in the final program. The Hypersonic Arbitrary-Body Aerodynamic Computer Program is no exception. Also, the desire to produce a workable tool within a reasonable time has had a strong influence on both the theoretical methods used and on the programming approach selected.

The various limitations and restrictions of this program have been discussed in the various sections of this report and are summarized in the following discussions. It is probable that future versions of this program, both by the original programmer and by the various users, will remove many of these conditions.

1. Three-Dimensional Effects - The geometry techniques in this program are capable of describing completely arbitrary three-dimensional shapes. However, the state of the art in force calculation methods, both inviscid and viscous, does not provide this freedom. A variety of force methods have been provided in the program to help alleviate this problem. However, all of these methods (except the shock-expansion method) depend only on the local slope of each individual element. General three-dimensional effects and the possible interactions of the various vehicle components are not accounted for by this program. Specific configurations where these effects become important include those vehicles especially designed to utilize interference effects, and multi-surfaced configurations where interacting flow fields are important. For these types of problems the user must rely on specialized techniques and programs designed specifically for the configurations involved.

2. Control Surface Effects - The control surface techniques used in this program are based on empirical separation correlations currently available. However, the general difficulty of this problem as evident in the large amount of scatter in the test data available and by the variety of answers given by the various theoretical techniques should give some forewarning as to the reduced accuracy of the results to be expected. The empirical correlations used in the program are based on data obtained on flat plate surfaces. While the program will continue to produce answers for conditions where the control surfaces are curved, the user should recognize that the limits of the method are being exceeded. It is felt, however, that the results obtained will more closely approximate the correct answers then if no attempt at all is made to include the separation effects.

PROGRAM ERROR NOTES	SUBROUTINE
A NON-FATAL ERROR OCCURRED IN PHASE XX. PROGRAM WILL ATTEMPT TO CONTINUE BY SEARCHING FOR NEXT TYPE = 99 CARD.	MAIN
**** BASIC INPUT FLAG ERRORS - SUBROUTINE PLUNGE IPART AND ICALC ARE XXXX XXXX **** TO ERR IS HUMAN	PLUNGE
*** CONGRATULATIONS - YOU HAVE HIT THE JACKPOT WITH AN ERROR INVOLVING EITHER CARD ORDER OR CARD TYPE INDICATION*** THE CARD LOCATED JUST BEFORE THE CARD LISTED BELOW IS IN ERROR	AERO
****DURING SHOCK-EXPANSION CALCULATIONS PROGRAM TRIED TO USE WRONG INITIAL ELEMENT METHOD--CHECK INPUT****	SHKEXP
***** ELEMENT DATA CONTROL CARD IS NOT PRESENT OR HAS THE WRONG TYPE NUMBER *****	SDATA
**** ELLIPTICAL INTEGRAL ERROR. T1 FROM PLUNGE IS NOT LESS THAN ONE AND GREATER THAN OR EQUAL TO ZERO	PLUNGE
***** FIRST PHASE OPTION IS ZERO ********** FATAL ERROR ****	MAIN
FOR SOME ODD REASON, TYPE CARD XX DOES NOT HAVE A XX IN COLUMN 71-72. BETTER LUCK NEXT TIME. WRITTEN BELOW IS THE IMAGE OF THE CARD FOLLOWING THE INCORRECT ONE	PLOT
***** FORCE ROUTINE WILL ATTEMPT TO FIND THE ARCCOSINE OF AN ARGUMENT WHOSE ABSOLUTE VALUE IS GREATER THAN ONE ***** *** JOB WILL BE TERMINATED ***	FORCE
**** INPUT MACH NUMBER IS NOT SUPERSONIC. SKIN FRICTION ANALYSIS FOR THIS POINT IS STOPPED ****	SKINFR
***** MASTER CONTROL CARD HAD TYPE NOT = 0 ******	MAIN
NO MORE SC-4020 DATA IS PLOTTED BECAUSE OF AN ERROR IN YOUR INPUT CARDS	PICTUR
***** NUMBER OF ALPHA-BETA CONDITIONS CANNOT BE GREATER THAN 20. JOB WILL BE ATTEMPTED WITH NAB = 20 *****	AERO
****NUMBER OF INITIAL ELEMENT CANNOT EXCEED 100 FOR SHOCK-EXPANSION CALCULATIONS. CHANGE INPUT DATA****	SHKEXP
**** NUMBER OF STREAMWISE ELEMENTS FOR CONTROL FORE-SURFACE AND FLAP CANNOT EXCEED 125 ****	FLOSEP
***** NUMBER OF STREAMWISE STRIPS ON FORE-SURFACE AND FLAP MUST BE THE SAME. CHANGE GEOMETRY DATA *****	SDATA
**** ON CONTROL SURFACE, ORIENTATION WAS INPUT AS = 0 PROGRAM CONTINUED WITH ORIENTATION SET = 1 ****	SDATA
***** PROGRAM HAS ATTEMPTED TO READ A ALPHA-BETA COMBINATION CARD WITH THE WRONG TYPE CODE*****	AERO
***** PROGRAM OPTION IS GREATER THAN 4 ******** FATAL ERROR ****	MAIN
***ROLL DERIVATIVE PART OF PROGRAM IS NOT OPERATIVE AT THE PRESENT TIME	AERO
**** SUBROUTINE PLUNGE SETS ERROR FLAG	PLUNGE
**** SUBROUTINE PLUNGE - THE FLAG ITYPE (WHICH CONTROLS EQUATION USED TO CALCULATE KBW) IS INCORRECT AND = XXXXX	PLUNGE
***** SURFACE DATA ROUTINE HAS ATTEMPTED TO READ A NON-SURFACE CARD - CHECK YOUR CARDS *****	SDATA
THE FOLLOWING CARD ON TAPE 8 IS IN ERROR	PICTUR
***** TOTAL NUMBER OF ELEMENTS ON CONTROL SURFACE CANNOT EXCEED 300 ***	CONTRL
*****YOU HAVE MADE AN ERROR EITHER IN CARD TYPE INDICATION OR CARD ORDER - CHECK YOUR CARDS***** THE CARD LOCATED JUST BEFORE THE CARD LISTED BELOW IS IN ERROR	PICTUR

SECTION VII

PROGRAM LIMITATIONS AND RESTRICTIONS

The degree of development of any computer program depends upon a number of factors. The limitations imposed by computer size and speed, the time and manpower available for formulation and programming, the general state of the art in the technical discipline - all influence to a large extent the capability provided in the final program. The Hypersonic Arbitrary-Body Aerodynamic Computer Program is no exception. Also, the desire to produce a workable tool within a reasonable time has had a strong influence on both the theoretical methods used and on the programming approach selected.

The various limitations and restrictions of this program have been discussed in the various sections of this report and are summarized in the following discussions. It is probable that future versions of this program, both by the original programmer and by the various users, will remove many of these conditions.

1. Three-Dimensional Effects - The geometry techniques in this program are capable of describing completely arbitrary three-dimensional shapes. However, the state of the art in force calculation methods, both inviscid and viscous, does not provide this freedom. A variety of force methods have been provided in the program to help alleviate this problem. However, all of these methods (except the shock-expansion method) depend only on the local slope of each individual element. General three-dimensional effects and the possible interactions of the various vehicle components are not accounted for by this program. Specific configurations where these effects become important include those vehicles especially designed to utilize interference effects, and multi-surfaced configurations where interacting flow fields are important. For these types of problems the user must rely on specialized techniques and programs designed specifically for the configurations involved.

2. Control Surface Effects - The control surface techniques used in this program are based on empirical separation correlations currently available. However, the general difficulty of this problem as evident in the large amount of scatter in the test data available and by the variety of answers given by the various theoretical techniques should give some forewarning as to the reduced accuracy of the results to be expected. The empirical correlations used in the program are based on data obtained on flat plate surfaces. While the program will continue to produce answers for conditions where the control surfaces are curved, the user should recognize that the limits of the method are being exceeded. It is felt, however, that the results obtained will more closely approximate the correct answers then if no attempt at all is made to include the separation effects.

3. **Real Gas Effects** - Except for the capability of using different values of the modified Newtonian factor, K, the present version of the program does not contain any methods where real gas effects are accounted for. Those computations in the program requiring oblique shock or Prandtl-Meyer results assume a perfect gas with $\gamma = 1.4$.

4. **Viscous Separation** - Except for control surface components the program contains no techniques for accounting for the effects of viscous separation on surface pressures. This must be accomplished by the proper selection of the pressure calculation methods by the user so that any known separation effects are simulated.

5. **Viscous Cross-Flow Effects** - The program does not account for viscous cross-flow effects. These effects must be calculated external to the program and added to the other program-produced results by the use of the Coefficient Increment Data cards.

6. **Vortex Effects** - The program makes no attempt to calculate the effects of complex vortex flow fields that may be present on some configurations. The effects of shed vortex patterns on downstream components is also neglected.

7. **Mach Number Limitations** - The program contains no inherent Mach number limitations (except that it must be greater than one). However, as has been discussed in other sections of this report, each of the various force calculation methods has its own limitations as to range of applicability with respect to Mach number and vehicle shape.

8. **Propulsion System Effects** - The effect of such items as flow separation and pressure changes caused by engine inlet and exhaust flow are not included in this program.

9. **Boundary Layer Transition** - The program does not determine when the flow is laminar or turbulent. The user must make this selection himself and input the appropriate flag to the program when required.

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APPENDIX A

FORCE CALCULATION METHODS

An important feature of the Hypersonic Arbitrary-Body Program is the number and variety of force calculation methods available to the user. The significance of this capability can be felt in two ways. First, a proper choice of the method to be used on each component of a vehicle will give reliably accurate aerodynamic characteristics. Second, when the choice of methods is not clear several methods may be tried, the results compared, and a logical interpolation of the data used. The analysis of arbitrary complex shapes poses a difficult problem for the aerodynamicist as he must decide for a particular shape, Mach number, angle of attack range, and altitude, which pressure calculation method will give the most correct results. No computer program will be able to relieve the aerodynamicist of this task. Thus the quality of answers which can be obtained is related to the personal background and experience of the program user in the area of hypersonic aerodynamics. Of course, if the program does not contain a pressure method suitable for a given problem, the user must attempt to devise on and add it to the program.

This Appendix presents a brief comparison of the various pressure calculation methods provided in this program. To assist the less experienced user a brief discussion is also presented of the more important pressure methods and of the key factors involved in selecting a method for a particular application.

COMPARISON OF METHODS

Presented in this section is a comparison of the force calculation methods available within the program. The comparison has been divided into three groups: (1) analysis techniques generally used for pointed slender configurations, (2) analysis methods for blunt shapes, and (3) force predictions in the free molecular regime.

Figures A-1 and A-2 present the pressure coefficient variation with impact angle for analysis techniques generally used on pointed slender components. Also presented for comparison purposes is the modified Newtonian theory with $K = 2.4$. This is the limiting value for wedge type flow as proposed by Lees in Reference 4. Figures A-3 to A-6 present the same data over a smaller impact-angle range. At $M = 20$ the modified Newtonian and the tangent-wedge empirical methods compare favorably with the "exact" oblique-shock calculations for impact angles from 0 to over 30°.

Figures A-7 and A-8 present a comparison of various techniques for both pointed and blunt configurations in expansion flow. It should be noted that the Van Dyke Unified method for expansion flow has been modified such that if a pressure coefficient of less than $-1/M^2$ is calculated for a given expansion angle the pressure coefficient is set equal to $-1/M^2$. This limiting value of pressure coefficient has been derived from analysis of experimental data (see References 5 and 6).

Blunt-body pressure-coefficient calculations are compared in Figures A-9 to A-12. The pressure-coefficient variation with impact angle is plotted in the form $C_p/C_{p_{STAG}}$ as suggested by Lees in Reference 4. The calculations for Newtonian Prandtl-Meyer and OSU empirical techniques utilized stagnation conditions behind a normal shock in an ideal gas.

Comparison of Free Molecular Flow calculations by the program and data presented in Reference 7 are shown in Figures A-13 through A-16. Flat-plate lift and drag coefficients are compared in Figure A-13, assuming specular reflection. Figures A-14 and A-15 present the lift and drag of a flat plate for the more realistic diffuse-reflection assumption. Finally, the drag coefficient for a sphere with both specular and diffuse reflection assumptions is shown in Figure A-16.

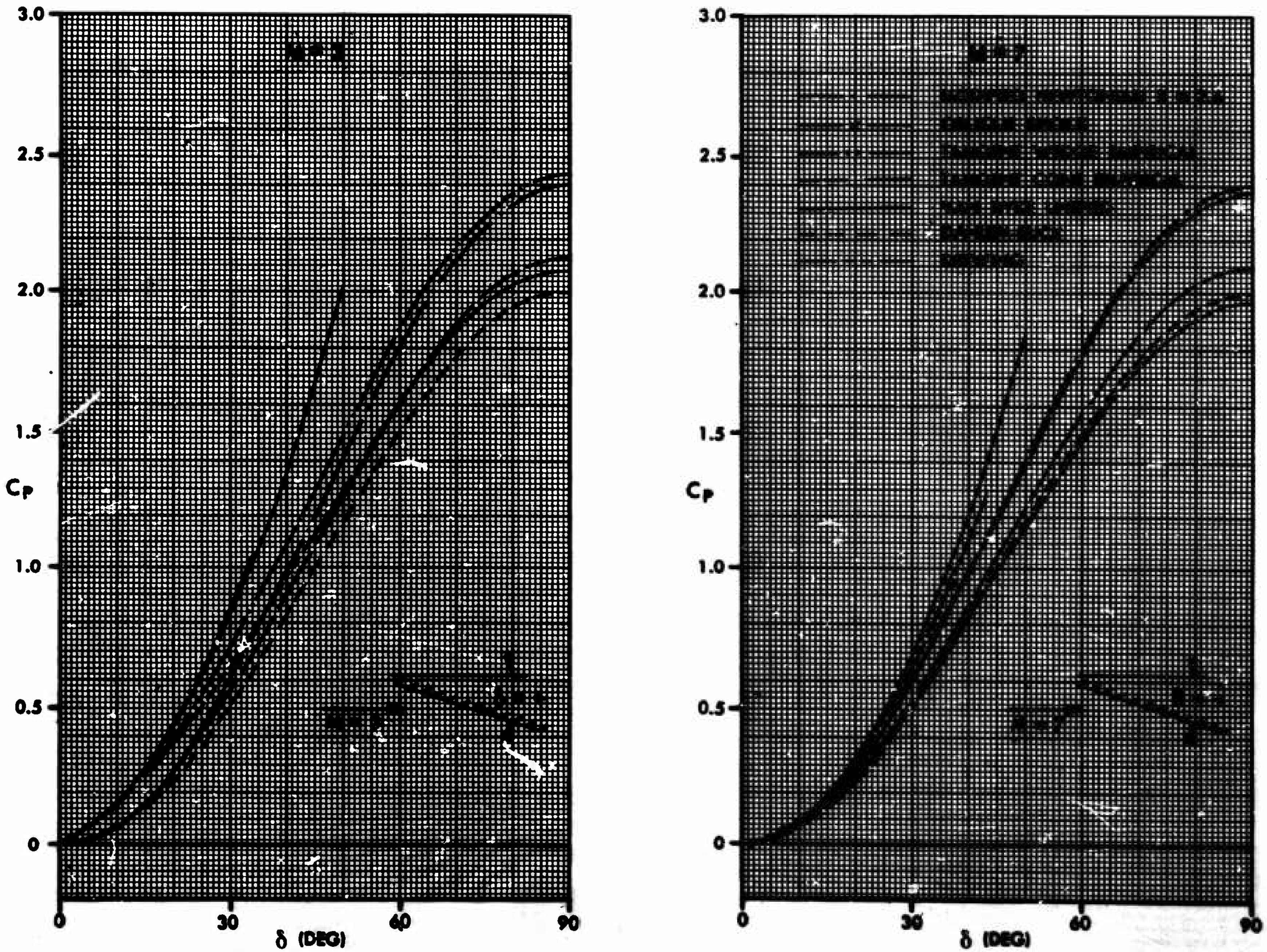


Figure A-1. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

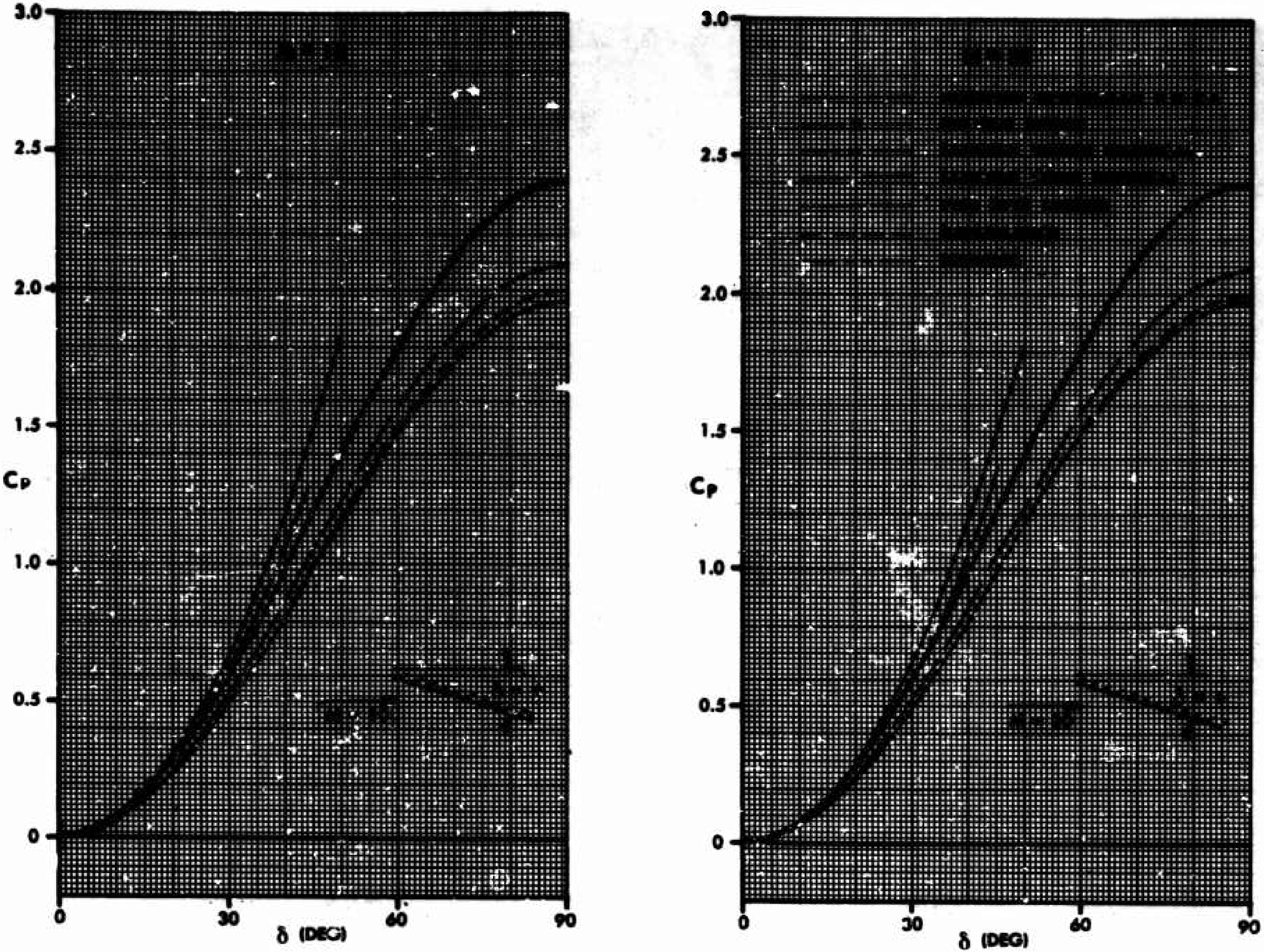


Figure A-2. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

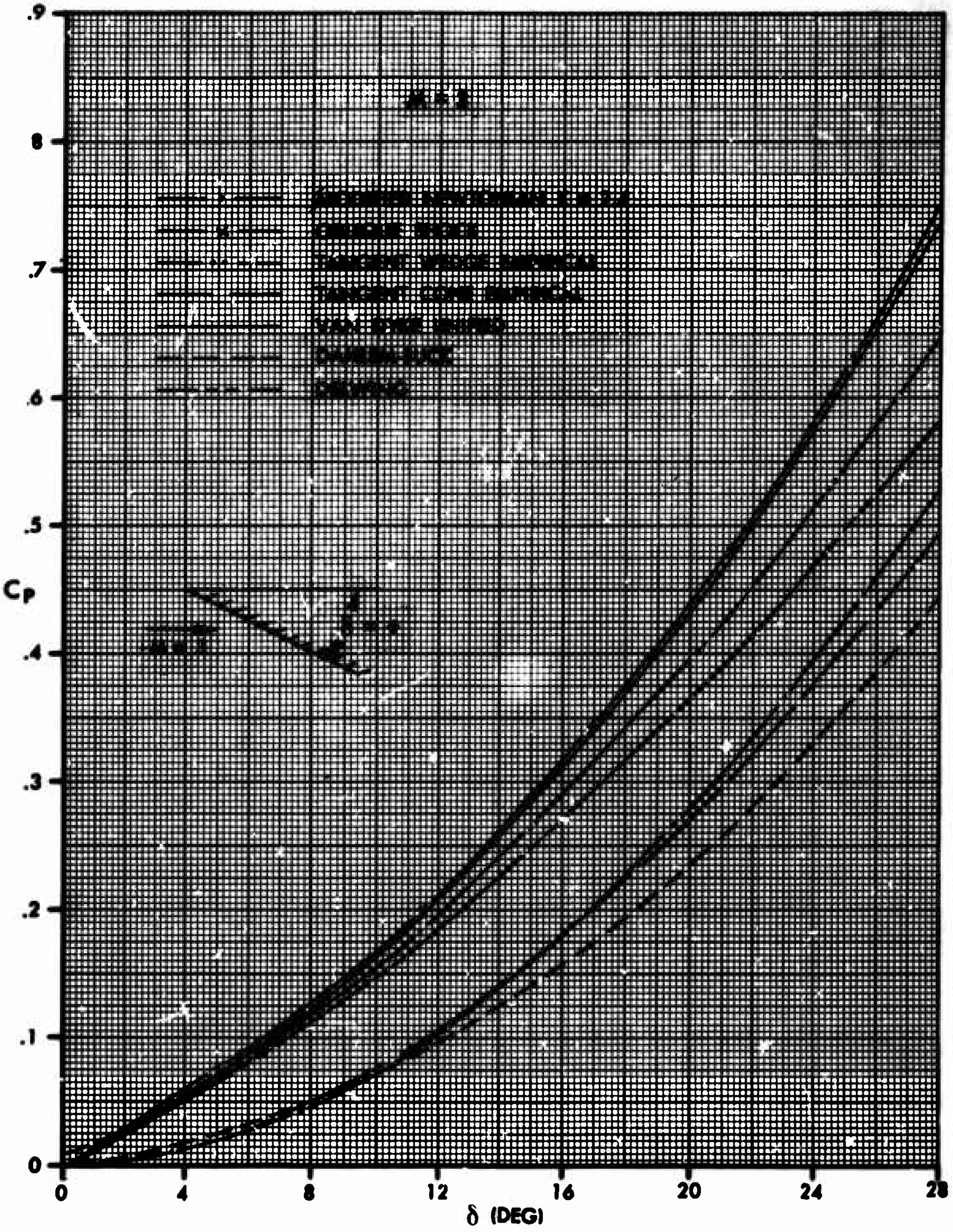


Figure A-3. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

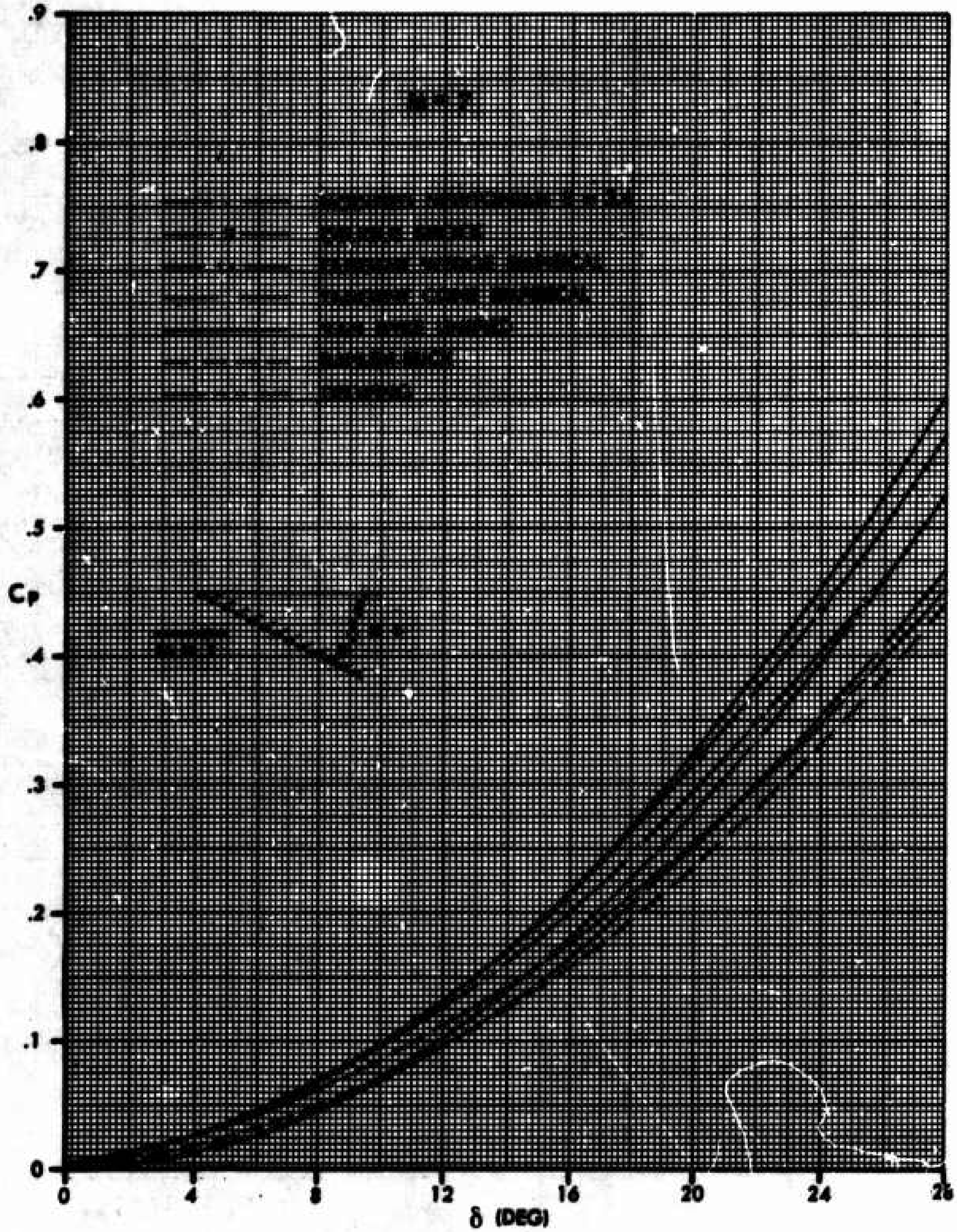


Figure A-4. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

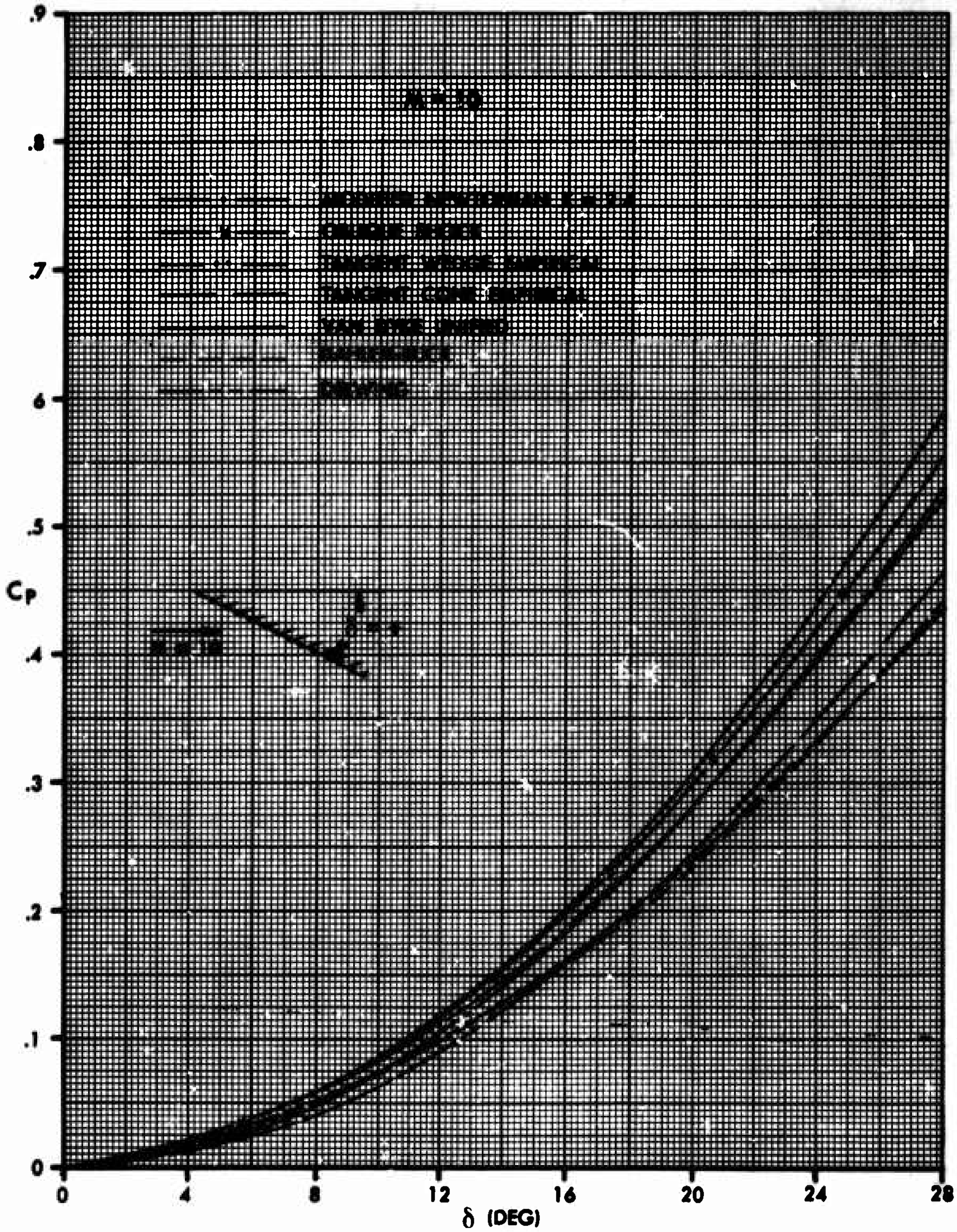


Figure A-5. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

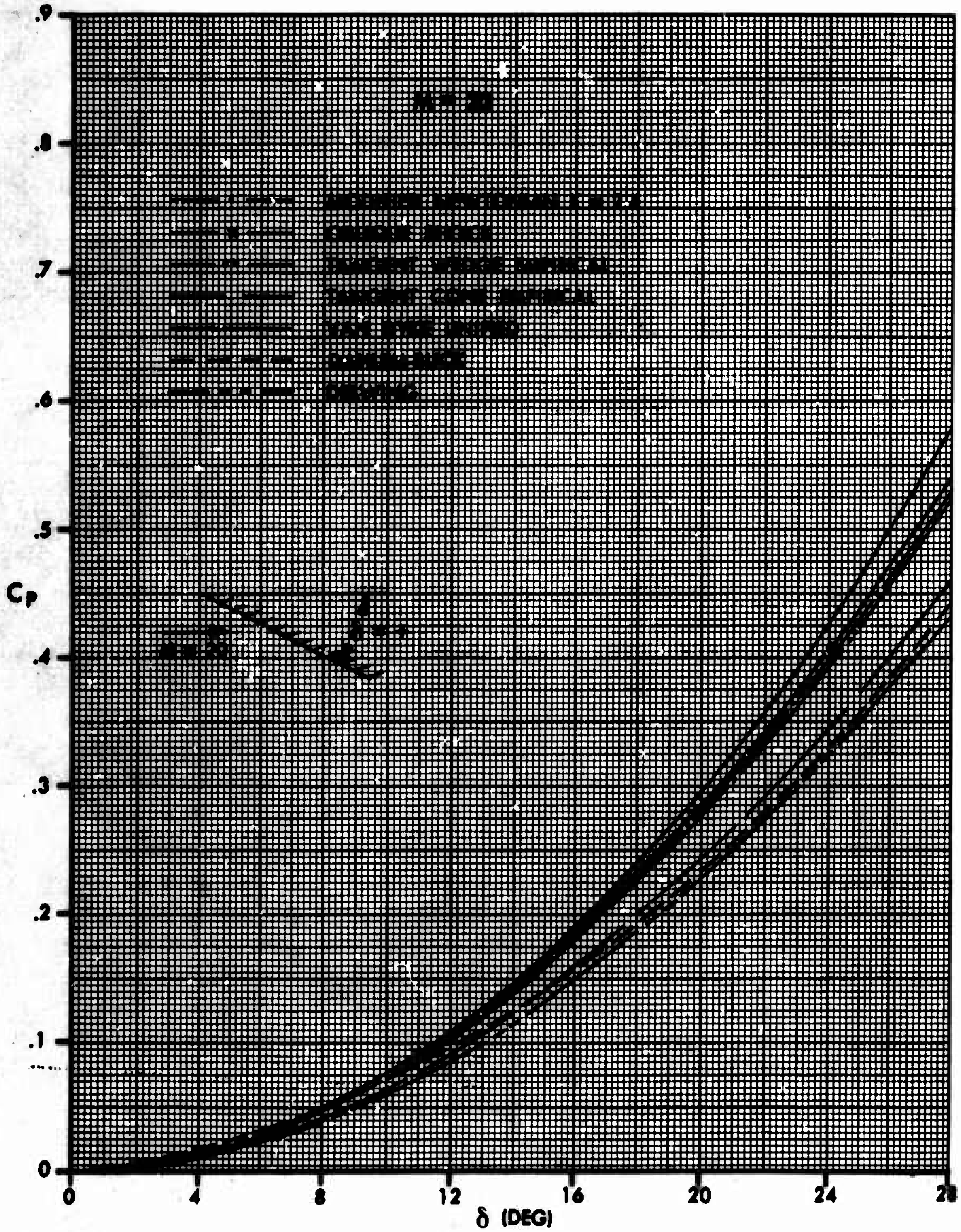


Figure A-6. Comparison of Pressure Prediction Methods for Sharp Bodies in Compression Type Flow

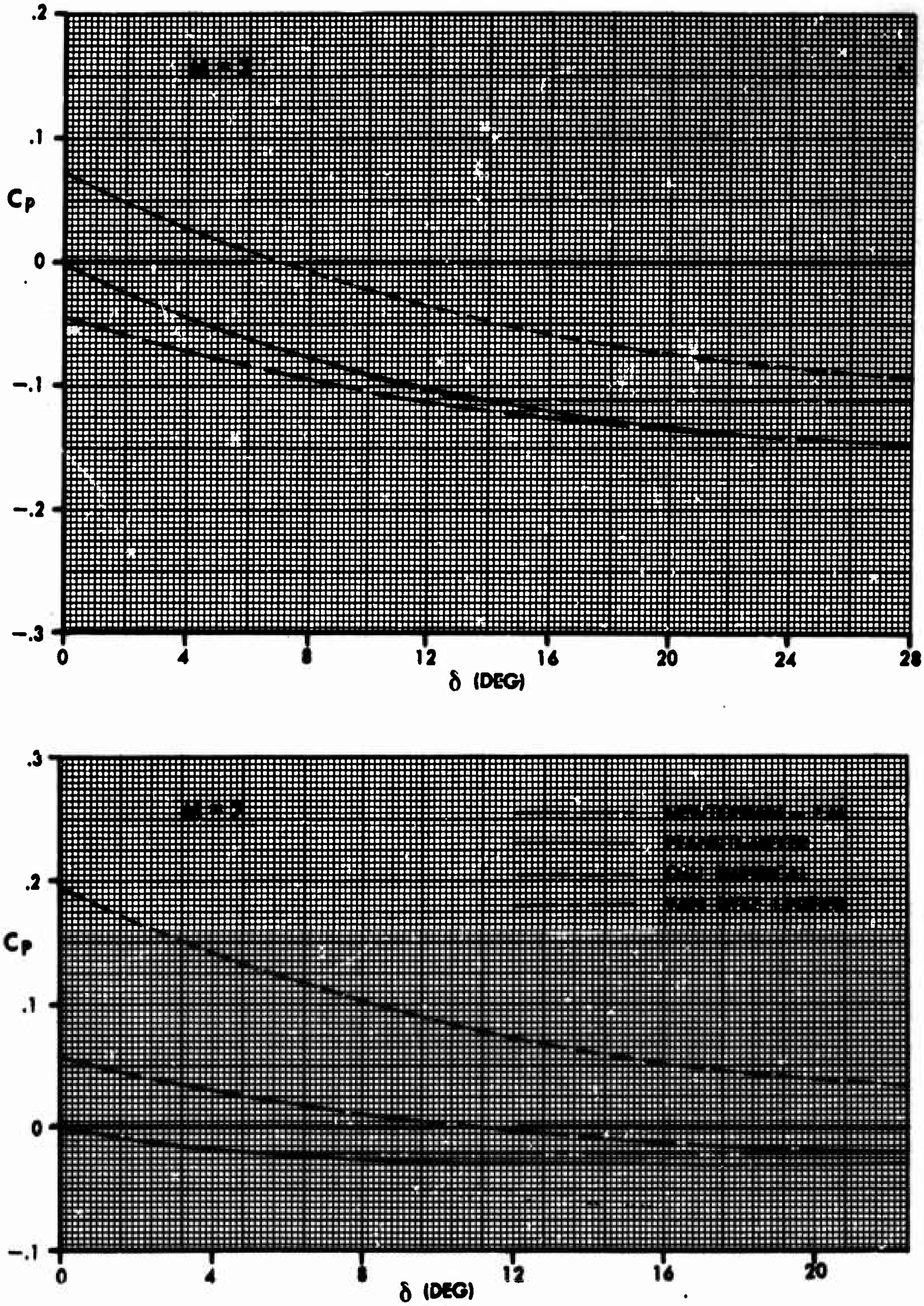


Figure A-7. Comparison of Pressure Prediction Techniques for Expansion Type Flow

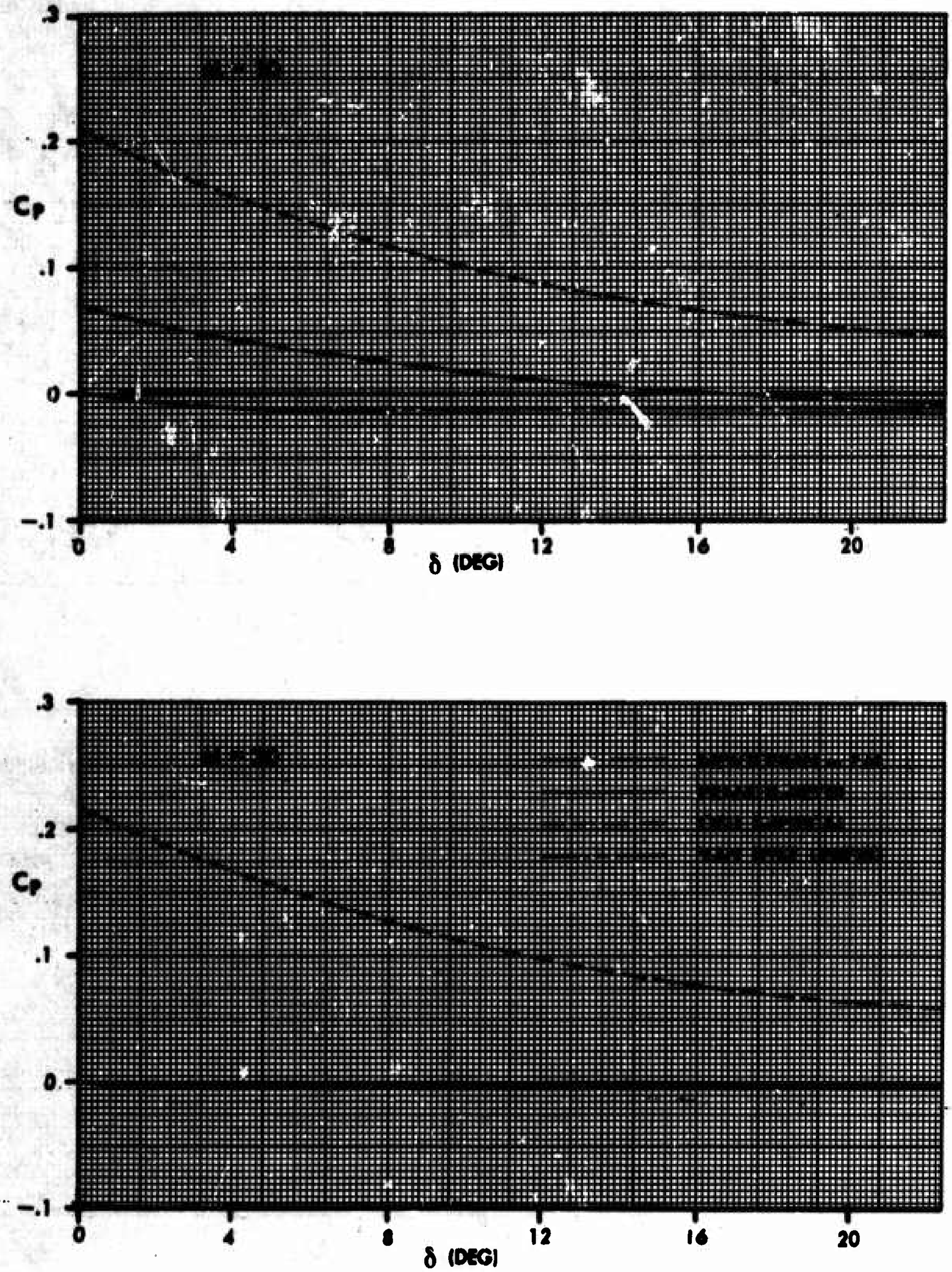


Figure A-8. Comparison of Pressure Prediction Techniques in Expansion Type Flow

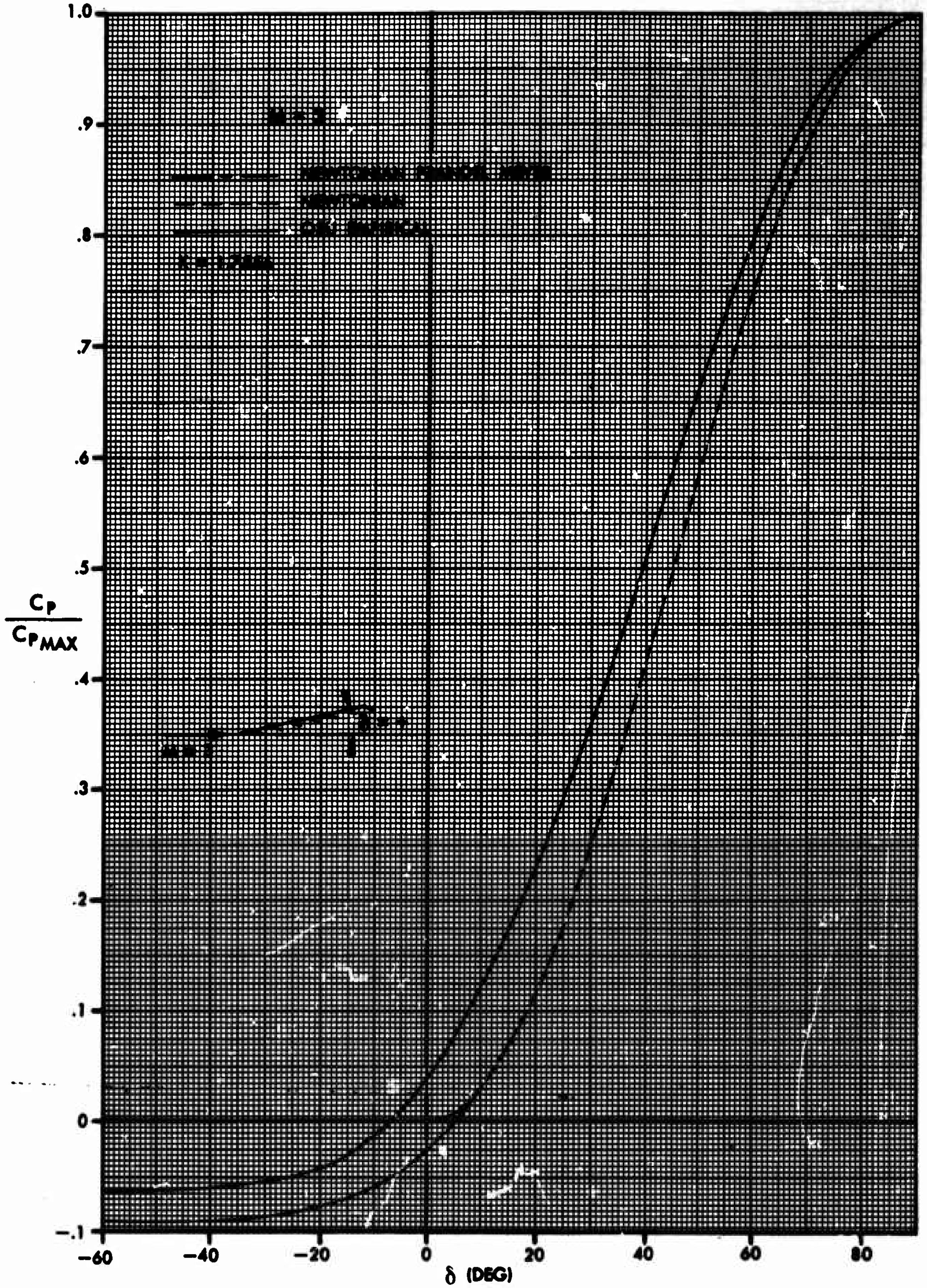


Figure A-9. Comparison of Blunt Body Pressure Estimation Techniques

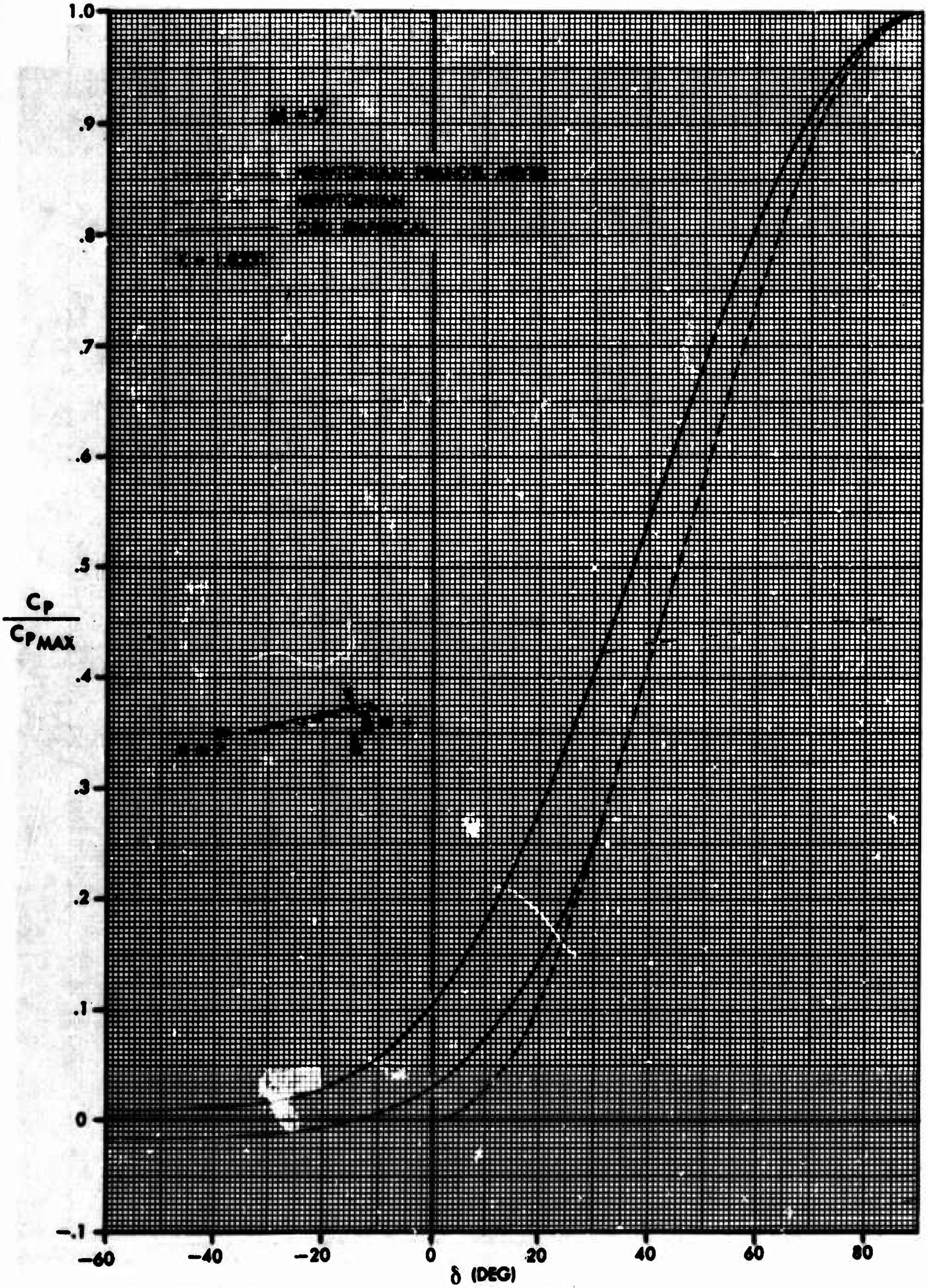


Figure A-10. Comparison of Blunt Body Pressure Estimation Techniques

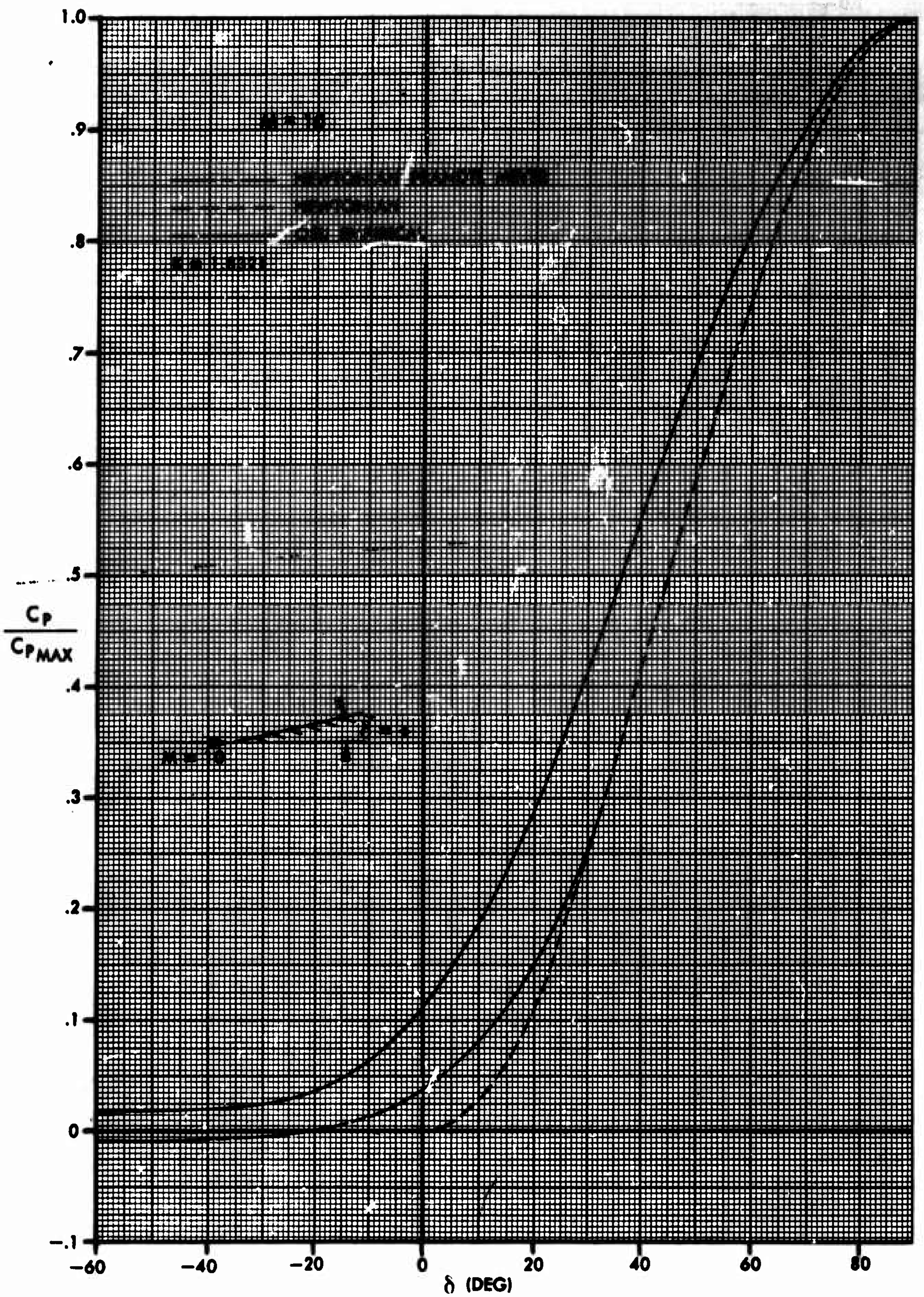


Figure A-11. Comparison of Blunt Body Pressure Estimation Techniques

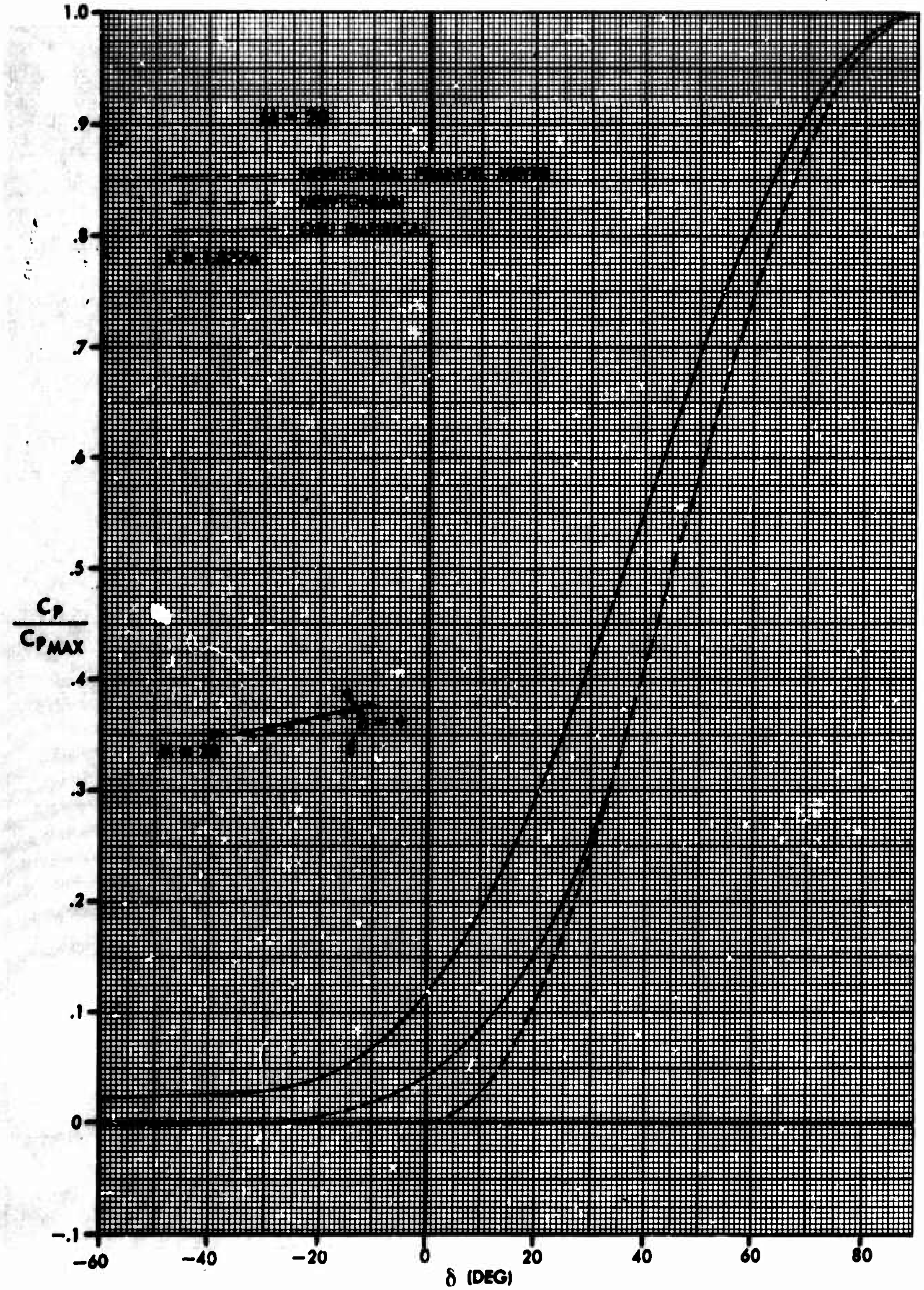


Figure A-12. Comparison of Blunt Body Pressure Estimation Techniques

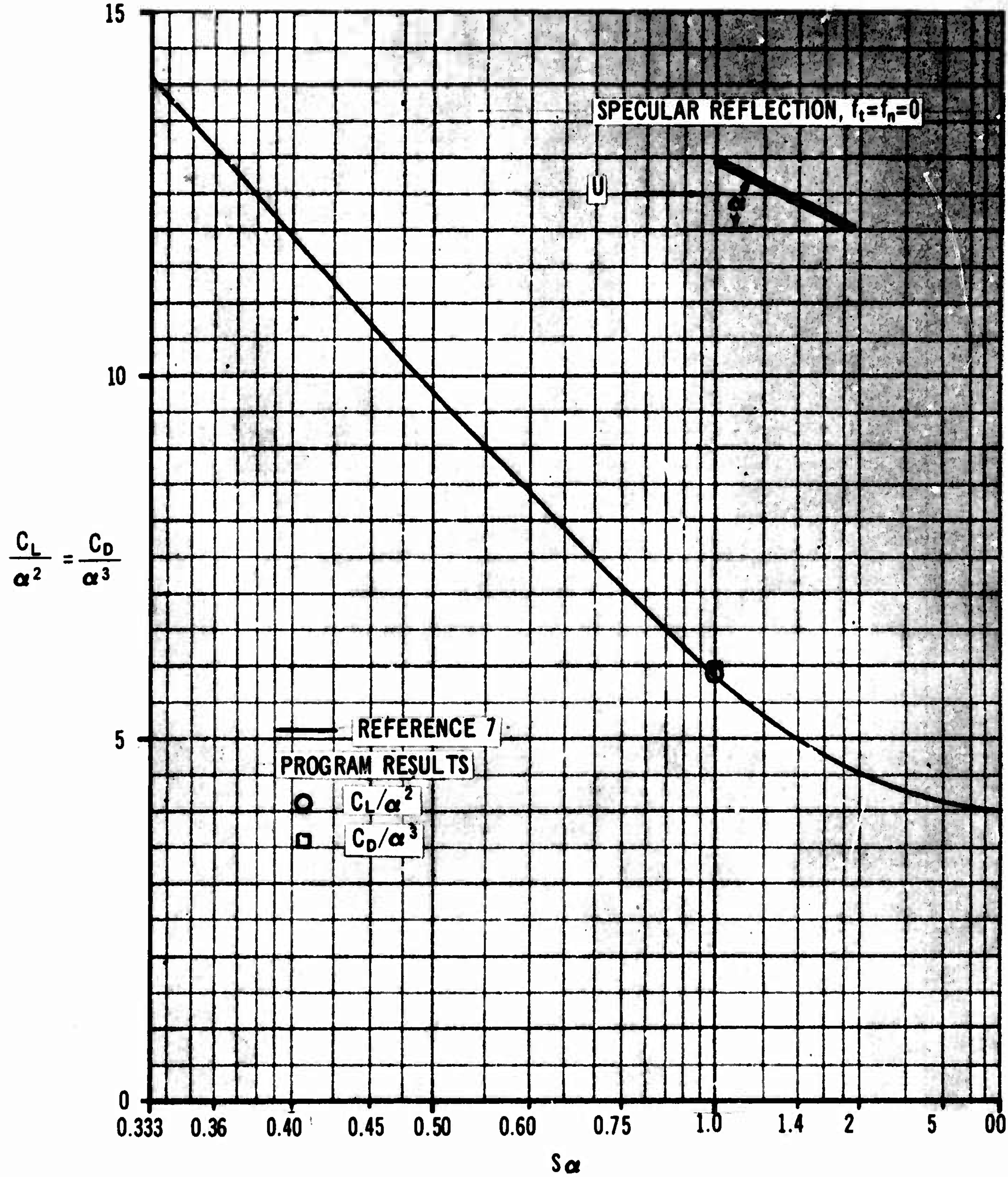


Figure A-13. Comparison of Free Molecular Flow Lift and Drag for a Flat Plate with Specular Reflection

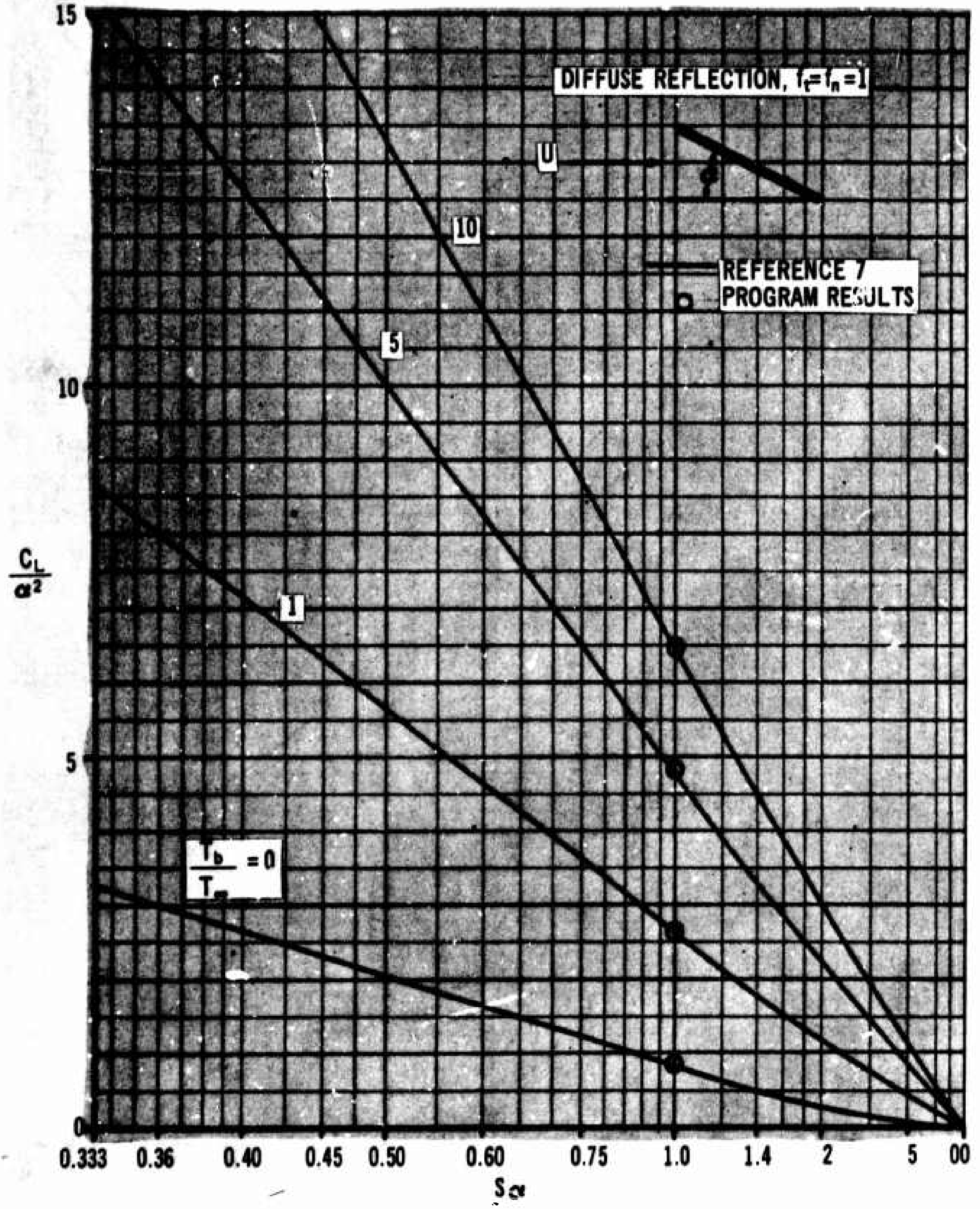


Figure A-14. Comparison of Free Molecular Lift on a Flat Plate with Diffuse Reflection

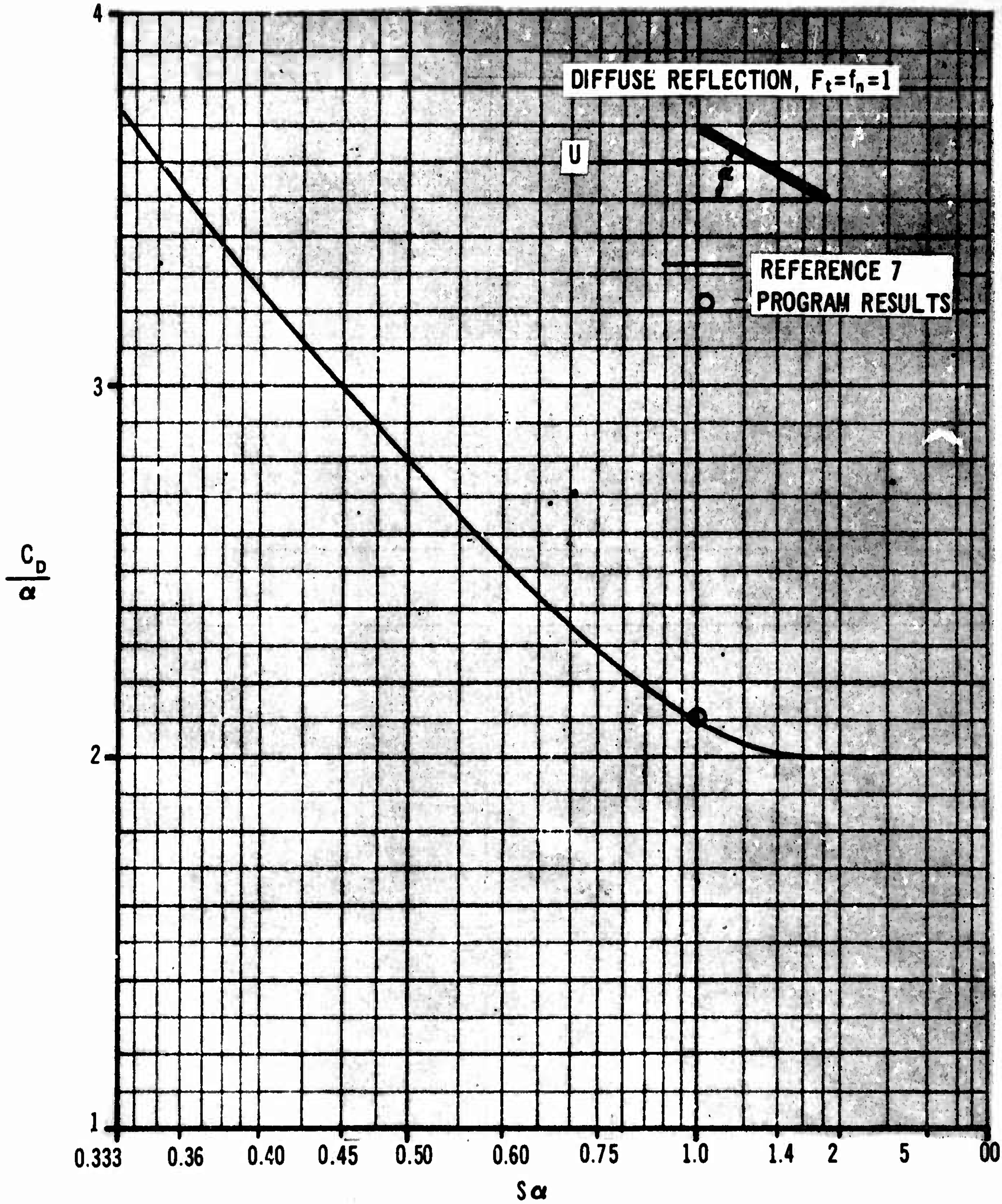


Figure A-15. Comparison of Free Molecular Drag on a Flat Plate with Diffuse Reflection

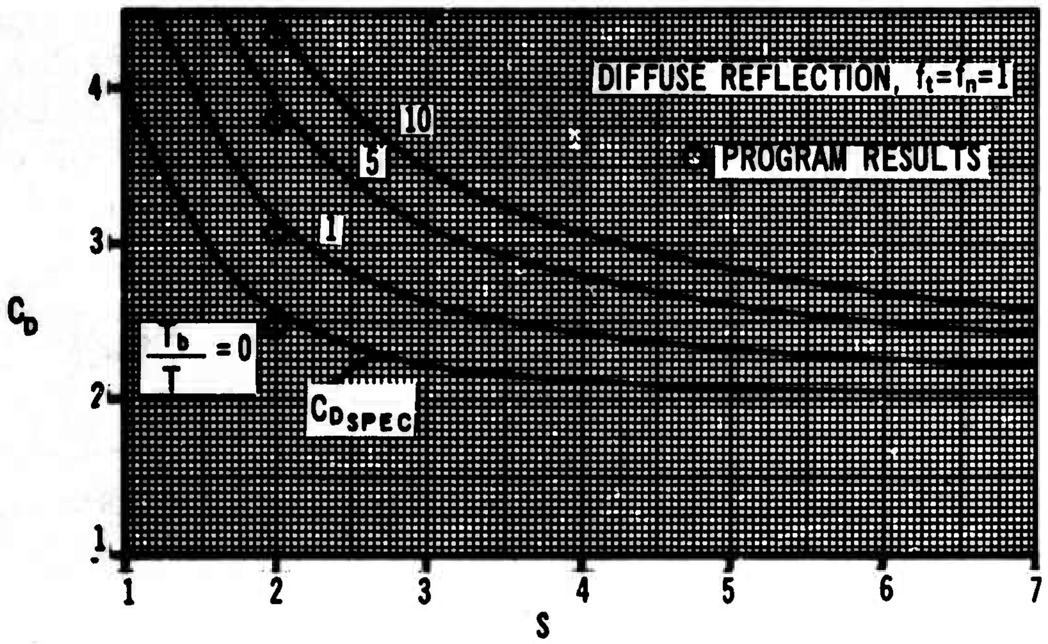


Figure A-16. Comparison of Free Molecular Drag on a Sphere with Diffuse Reflection

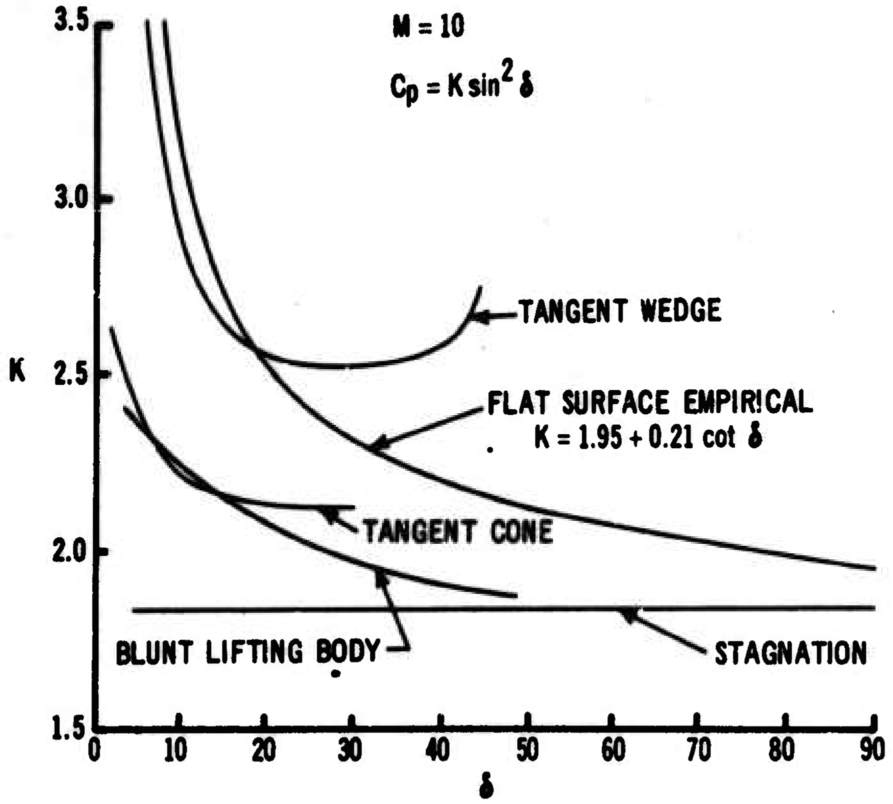


Figure A-17. Modified Newtonian Correlation Factors

DISCUSSION OF PRESSURE METHODS

A brief review of the important features of some of the pressure calculation methods in the program is presented in the following discussions.

MODIFIED NEWTONIAN

Modified Newtonian is one of the most extensively used methods in hypersonic flow analysis. Its great utility lies in its ability to give reasonable answers for a great number of shapes with a very simple calculation technique. The capabilities derived from the ability to use variable K as a function of angle of attack is shown in Figure A-17. As shown in this figure the Modified Newtonian form permits application of tangent wedge (or tangent cone), an empirically defined equation for a given shape, or an effective K for a complete configuration at a given Mach number. Also the effect of a real gas may be introduced by variation of K for very blunt bodies. In general the use of modified Newtonian theory may be divided into two groups for discussion purposes, (1) aerodynamically blunt configurations and, (2) aerodynamically sharp configurations. By aerodynamically blunt configurations it is meant that, although the leading edge may be sharp and pointed, the impact angle of the nose is greater than that for shock detachment. In true Newtonian flow ($M = \infty$, $\gamma = 1$) the variable K becomes 2.

Modified Newtonian (K other than 2) techniques have been shown to give reasonable results for a number of blunt bodies. The most commonly used form of modified Newtonian is to input for K the C_p stagnation derived from normal shock relations into the equation below.

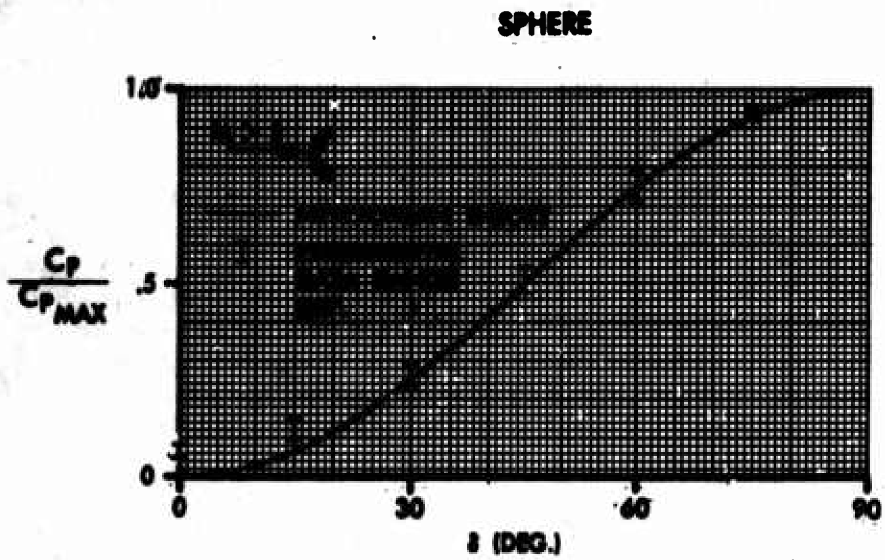
$$C_p = K \sin^2 \delta$$

The effects of a real gas may also be approximated in this manner. The comparison of Newtonian and experimental data is presented in References 13 to 15 for blunt body shapes. In general, modified Newtonian ($C_{p_{STAG}} = K$) agrees with data for spheres if the Mach number is greater than 3. The pressure distribution on cylinders is not as good as on spheres. However, for impact angles of 90 degrees to approximately 60 degrees the agreement is reasonable but deteriorates as zero impact angle is reached. Nevertheless, for preliminary calculations the induced error in C_N and C_A may be acceptable.

Examples of the comparison of modified Newtonian and experiment for spheres and cylinders are shown in Figure A-18. For curved, shock detached bodies with sharp leading edges of either two or three-dimensional shape, References 16 and 17 show that $C_p = K \sin^2 \delta$ should be modified to the form

$$\frac{C_p}{C_{p\,max}} = \frac{\sin^2 \delta}{\sin^2 \delta\ max}$$

which is sometimes called the generalized Newtonian theory. Comparison with other bodies is shown in Reference 8.



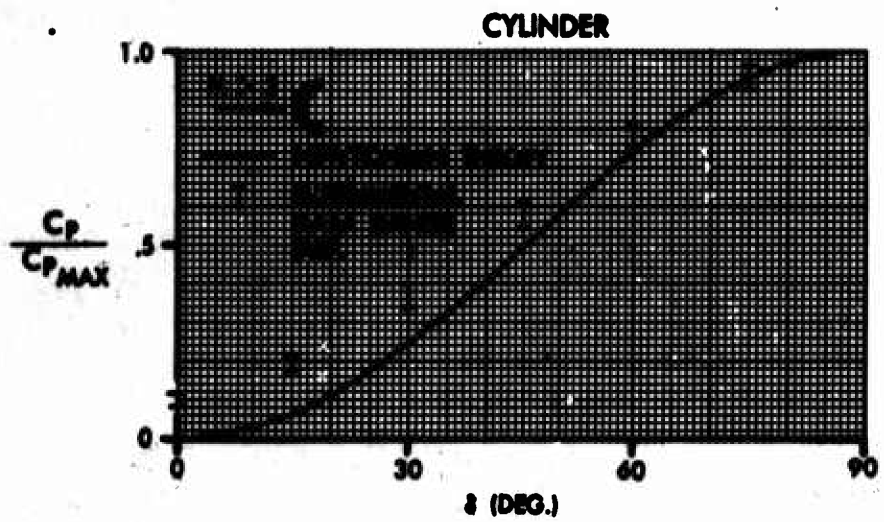


Figure A-18. Comparison of Experimental Pressures and Modified Newtonian Theory for Spheres and Cylinders

Many approximations exist for sharp pointed bodies. Figures A-13 through A-16 include one form for the sharp wedge developed by Lees in Reference 4 for large Mach numbers.

$$K = (\gamma + 1)$$

Also shown is the limiting form of the cone

$$K = \frac{2(\gamma + 1)(\gamma + 7)}{(\gamma + 3)^2}$$

For large Mach numbers true Newtonian theory, therefore, closely approximates the limiting case for a cone rather than a wedge.

The main disadvantage of Newtonian theory is its inability to predict the flow field, and for some shapes, this effect can lead to predicted values which may be in serious disagreement with theory. Seiff in References 9 and 10 presents examples of these shapes and a method for obtaining more realistic results from a Newtonian flow concept.

MODIFIED NEWTONIAN + PRANDTL-MEYER

One of the several procedures for analyzing pressures on blunt leading edges is the Newtonian approximation. However, the Newtonian Calculations decrease in accuracy downstream of the stagnation point where the impact angle approaches zero. The Modified Newtonian + Prandtl-Meyer calculation method improves the accuracy in the region of small impact angles. This method is fully described in Reference 11. The method provided in the Mark II program does not include real gas effects. It should be noted that for some flight conditions the effective value of γ may change significantly across the normal shock, for equilibrium flow of a real gas. In using this method a free stream Mach number greater than about 3 is required because of the matching techniques used for the pressure slopes. If this method is utilized for relatively sharp corners in supersonic flow the methods described above do not allow for the recompression that occurs further downstream. Also, incorrect pressures would be calculated if the slope approaches zero a large distance from the blunt nose since the effect of the reflected expansion waves is neglected. Sweep effects are not calculated using this method at the present time (i. e., the parameter P is calculated using the freestream Mach number). Thus the modified Newtonian + Prandtl-Meyer force method should be used only in the region of the nose of a blunt body.

TANGENT WEDGE (Oblique Shock)

This force method utilizes the equations of NACA TR-1135 (Reference 12) to calculate the oblique shock pressure and flow parameters. When the impact force method is 3 in the Arbitrary-Body Program the tangent-wedge

approximation is applied by using the oblique shock relationships at the local element impact angle and free stream Mach numbers. The shock-expansion method is another mode of operation that uses the oblique shock relationships.

The tangent wedge (oblique shock) method provided in the program is used right up to the wedge shock detachment angle. At higher local impact angles the program automatically switches to the Newtonian + Prandtl-Meyer method. This will give a discontinuity in pressure coefficient as the shock detachment point is passed. This problem can be avoided by the use of empirical tangent-wedge relationships.

As this tangent wedge method is empirical in nature, the accuracy for pressure calculation is configuration dependent. Basically, the tangent wedge approximation depends on the very thin shock layer frequently present at hypersonic speeds. That is, since the shock layer is thin and close to the body there is little change in the flow inclination or the pressure as one proceeds outward from the surface toward the shock. Thus the values at the surface are assumed to be those immediately behind the shock. The shock angle and related flow parameters are determined by the application of the oblique shock method to a wedge whose half angle equals the local impact angle of the body with respect to the free stream velocity vector.

In order to apply the tangent wedge approximation with some degree of confidence the following criteria should hold: (i) the body shape immediately upstream of the point of interest must not be blunt, (ii) the density ratio across the shock should be small, and (iii) the body curvature should be small, such that centrifugal pressure effects are negligible. These centrifugal force effects give rise to a pressure gradient across the shock layer. Also, these pressure gradients cause the streamlines to change shape and give a gradient in inclination angle across the shock layer.

TANGENT WEDGE EMPIRICAL

Comparison of the tangent wedge empirical method and oblique shock relationship is shown in Figures A-1 and A-2, and again in Figures A-3 through A-6. See TANGENT WEDGE (Oblique Shock) discussion for application criteria.

TANGENT CONE EMPIRICAL

One of the most versatile force calculation methods is the tangent cone empirical technique. The calculation of cones under various conditions of pitch and yaw are an obvious application. Another application is the highly swept delta wing. For leading edge sweep angles greater than 80 degrees and hypersonic Mach numbers above 10, the tangent cone pressures agree reasonably well for the lower surface pressure coefficients for impact angles greater than 10 degrees. A comparison of tangent wedge and tangent cone calculations for delta wings of various leading edge sweeps is presented in Figure A-19. The experimental data presented are from Reference 13. These data were obtained with helium as a test gas and a test Mach number of 20.3. The sharp leading edge and the t/L = .01 data are presented with

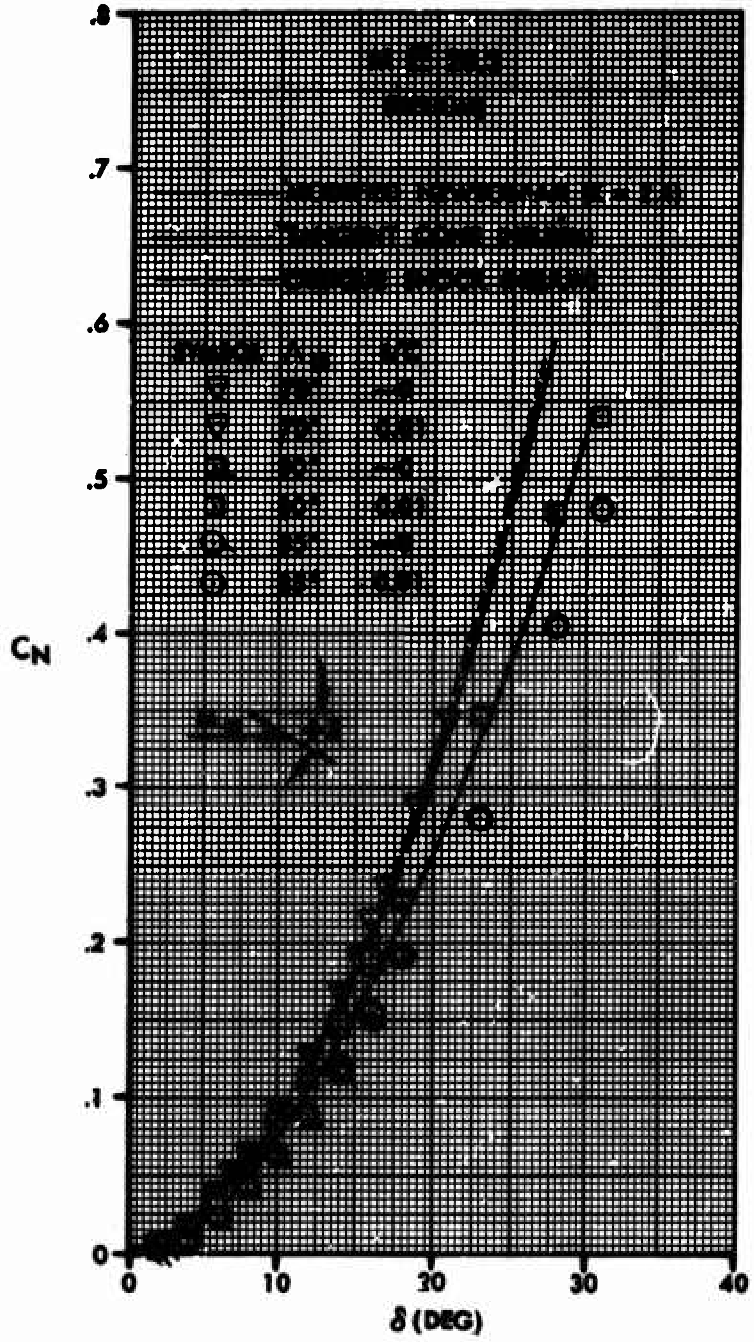


Figure A-19. Comparison of Oblique Shock and Tangent Cone Theories with Experimental Data for Highly Swept Delta Wings

the sharp leading edge data flagged. Oblique shock characteristics and tangent cone characteristics were calculated by the curves of Reference 14 for helium. The tangent cone approximation agrees well with the 85° sweep data at low angles, and with the 80° sweep at the higher angles of attack. On the other hand, the oblique shock tangent wedge calculations agree over most of the angle of attack range with the 70° sweep case. From the data presented for angles of attack greater than 10 degrees the tangent cone empirical method would give reasonable values for an 80 degree swept delta wing. Also shown for comparison purposes is the modified Newtonian estimate with $K = \gamma + 1$ (also see shock-expansion method discussion).

OSU BLUNT BODY EMPIRICAL

This blunt body empirical method is used to predict the pressure distribution about cylindrical surfaces in hypersonic flow. The empirical equation was derived in Reference 15 and matched the test data on cylinders within 2.5 percent. The method as used in the Mark II program is not applicable to the calculation of the pressure distribution for swept cylinder due to the relationship between δ and ϕ for a swept leading edge, and the inability to calculate the total pressure immediately behind the normal shock along the swept leading edge stagnation point. Comparison of experimental and theoretical methods is presented in References 15 and 16.

VAN DYKE UNIFIED METHOD

In general this method is used for small deflection angles. Comparisons of the Van Dyke Unified method and oblique-shock and other methods may be obtained from Figures A-1 through A-6.

DAHLEM-BUCK EMPIRICAL

This method uses an empirical relationship that approximates tangent-cone pressures at low impact angles and approaches Newtonian values at the high impact angles. This method is particularly useful for highly swept shapes when it is desired to use one pressure method over the entire surface of the vehicle. The comparison of the Dahlem-Buck method and other techniques is shown in Figures A-1 through A-8.

SHOCK EXPANSION METHOD (Strip Theory)

The shock expansion method (which in its simplest form was first suggested by Epstein in Reference 17) considers only the first family of characteristics for calculation of the surface pressures. The method uses the oblique shock relationships at the nose (an attached shock is required) and then proceeds aft on the vehicle with either a Prandtl-Meyer expansion or another oblique shock. Three methods are available for the calculation of leading edge flow properties. These methods are: (1) tangent wedge (oblique shock) relationships, (2) the tangent cone empirical technique and (3) the delta wing empirical method discussed later in this section. With these three methods a wide range of aerodynamic shapes may be evaluated.

Numerous reports show that, for angles of attack up to shock detachment, the application of the shock expansion method (with oblique shock used for the calculation of the leading edge properties) gives good agreement with the aerodynamic characteristics of highly swept or delta wings in hypersonic flight. However, for large sweep angles or low hypersonic Mach numbers the angle of attack for leading edge detachment becomes very small (when considered normal to the leading edge) and the range of application is considerably reduced (see Reference 18). Under the detached leading edge condition tangent-cone shock-expansion gives reasonable results for highly swept wings (i.e., $\Lambda_{LE} \approx 80^{o}$) over moderate angle of attack range. As shown previously in Figure A-19, there is an effect of sweep at these high Mach numbers such that past shock detachment empirical techniques would have to be utilized to cover the complete range of sweep angles.

An example of the use of shock expansion method to calculate the surface pressure distribution on a two-dimensional airfoil is presented in Reference 19. The shock expansion method is compared with characteristics solution at $M = \infty$ and $\gamma = 1.4$ in Figure A-20. For all Mach numbers up to 7.5 it was found that the results obtained by the shock-expansion method were indistinguishable from the characteristics calculations. For higher Mach numbers a slightly lower pressure was predicted by the shock-expansion procedure. Naturally, any three-dimensional effects will tend to reduce the two-dimensional characteristics predicted by the shock-expansion method. However, due to the large Mach number, the possible regions of influence at the tips are small for moderate deflections.

Application of the generalized shock-expansion method to bodies of revolution is discussed in Reference 20. In this mode the leading edge properties are calculated by a tangent-cone and then the surface properties aft of the leading edge are calculated by a Prandtl-Meyer expansion. In general, the application of a two-dimensional calculation technique to three-dimensional bodies is possible when the divergence of streamlines in planes tangent to the surface can be considered negligible compared to those associated with the curvature of streamlines in planes normal to the surface. For the case of non-inclined bodies of revolution which are curved in the streamwise direction, this requirement is satisfied when the hypersonic similarity parameter $\kappa = M \frac{d}{l}$ is greater than one. For the more general lifting case an additional constraint of $\alpha/\sigma_{semivertex} = 1$ is introduced. Reference 20 notes that good correlation of pressure was obtained when $\alpha/\sigma = 1/2$ and fair agreement at $\alpha/\sigma = 1.0$. Results from this reference are presented in Figures A-21 and A-22. Application of the basic shock-expansion technique at lower values of κ to various bodies should not include shapes which have large lengths of zero curvature as this can lead to incorrect values with respect to experiment. The simple case of a cone cylinder is presented in Figure A-23 for an example of this error.

Another mode of operation for the shock expansion technique is in the calculation of flow separation characteristics on control surfaces. Again in this mode the three leading edge "starting" conditions are available for flow field definition. In the utilization of the shock expansion technique for

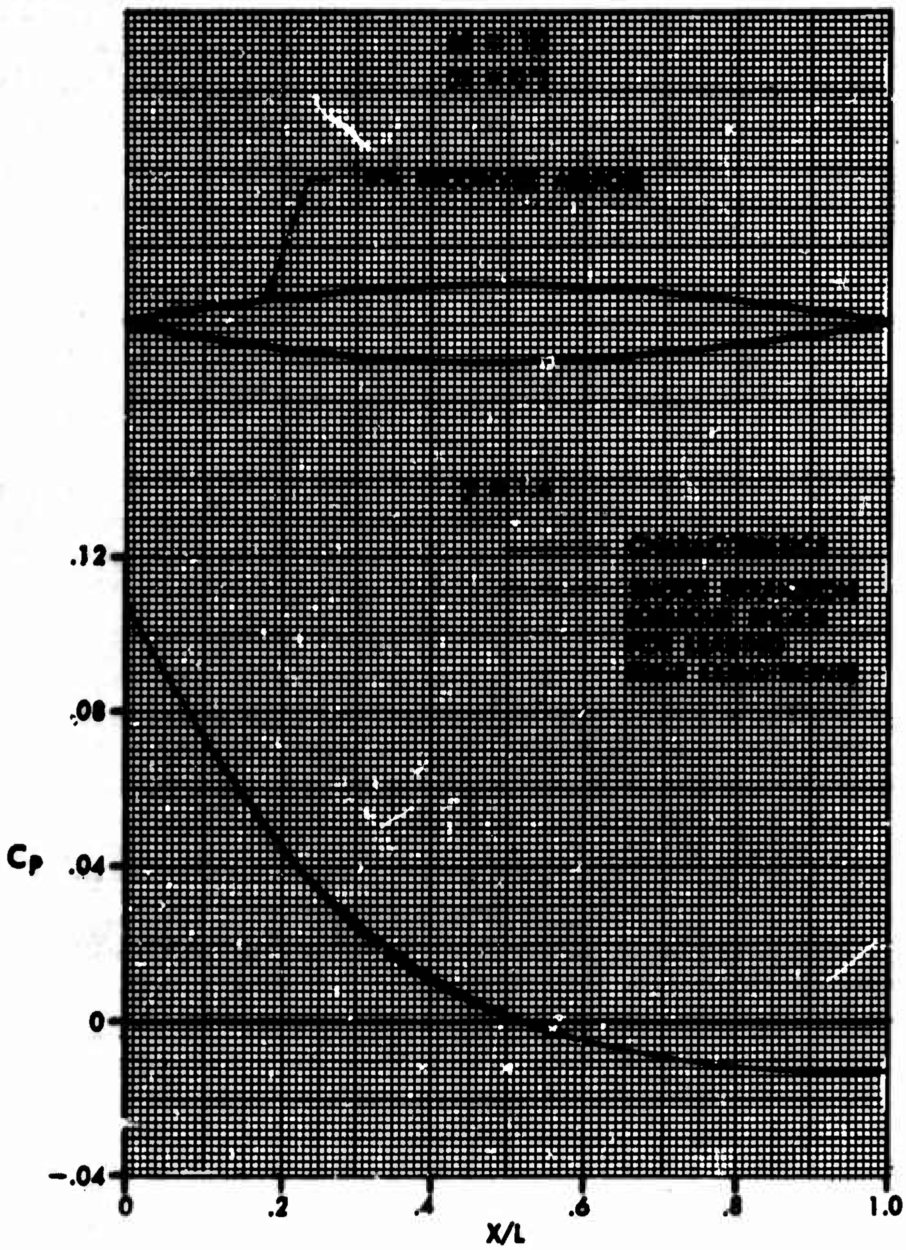


Figure A-20. Comparison of Shock Expansion and Characteristics Solution for the Surface Pressure Coefficient on a 10° Biconvex Airfoil

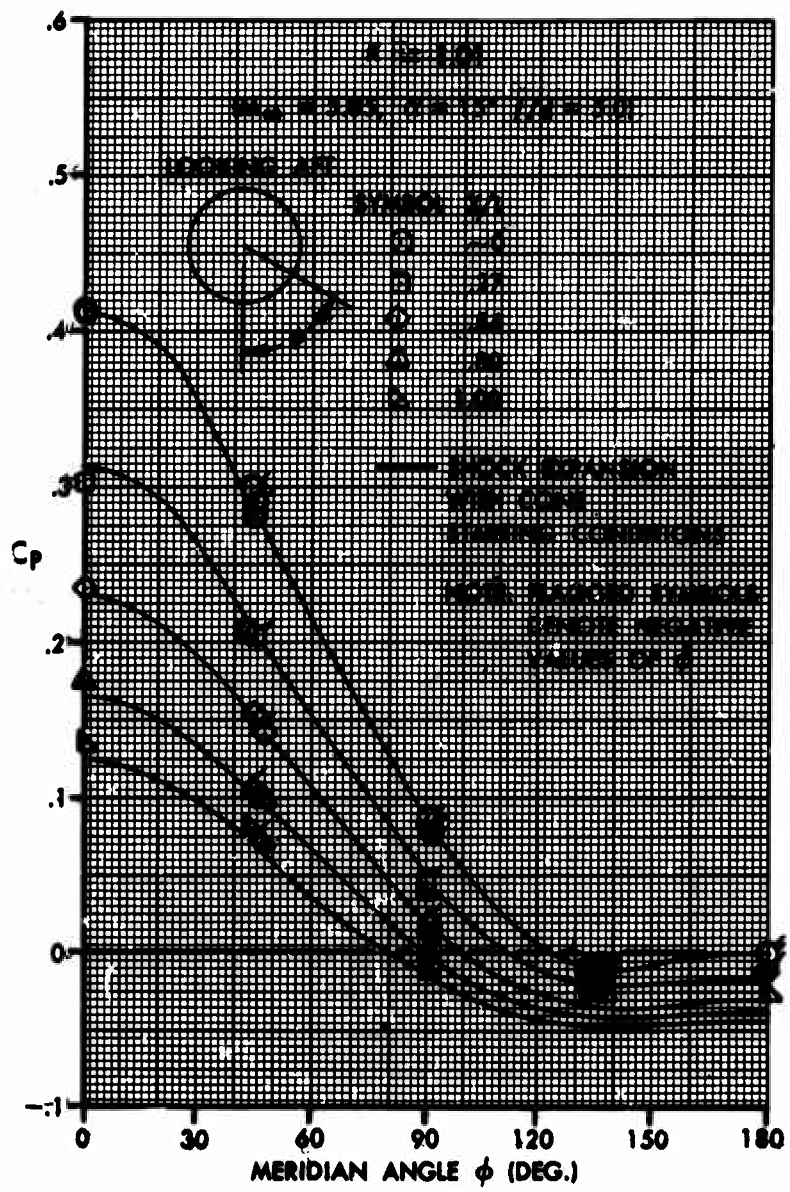


Figure A-21. Circumferential Variation of Pressure Coefficient on a Fineness Ratio 5 Ogive at 15 Degrees Angle of Attack

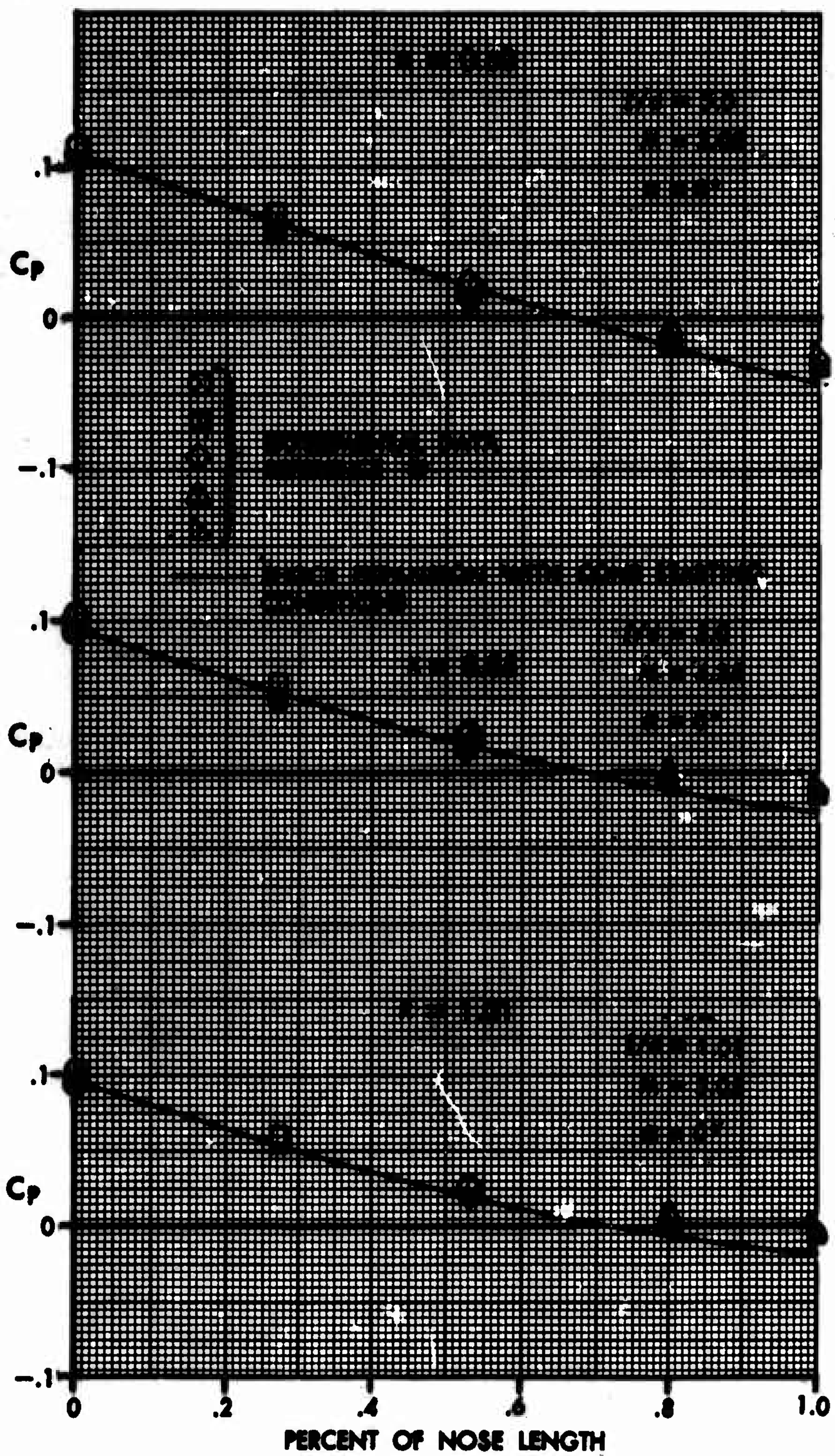


Figure A-22. **Variation of Pressure Coefficient Along a Fineness Ratio 5 Ogive at Zero Angle of Attack**

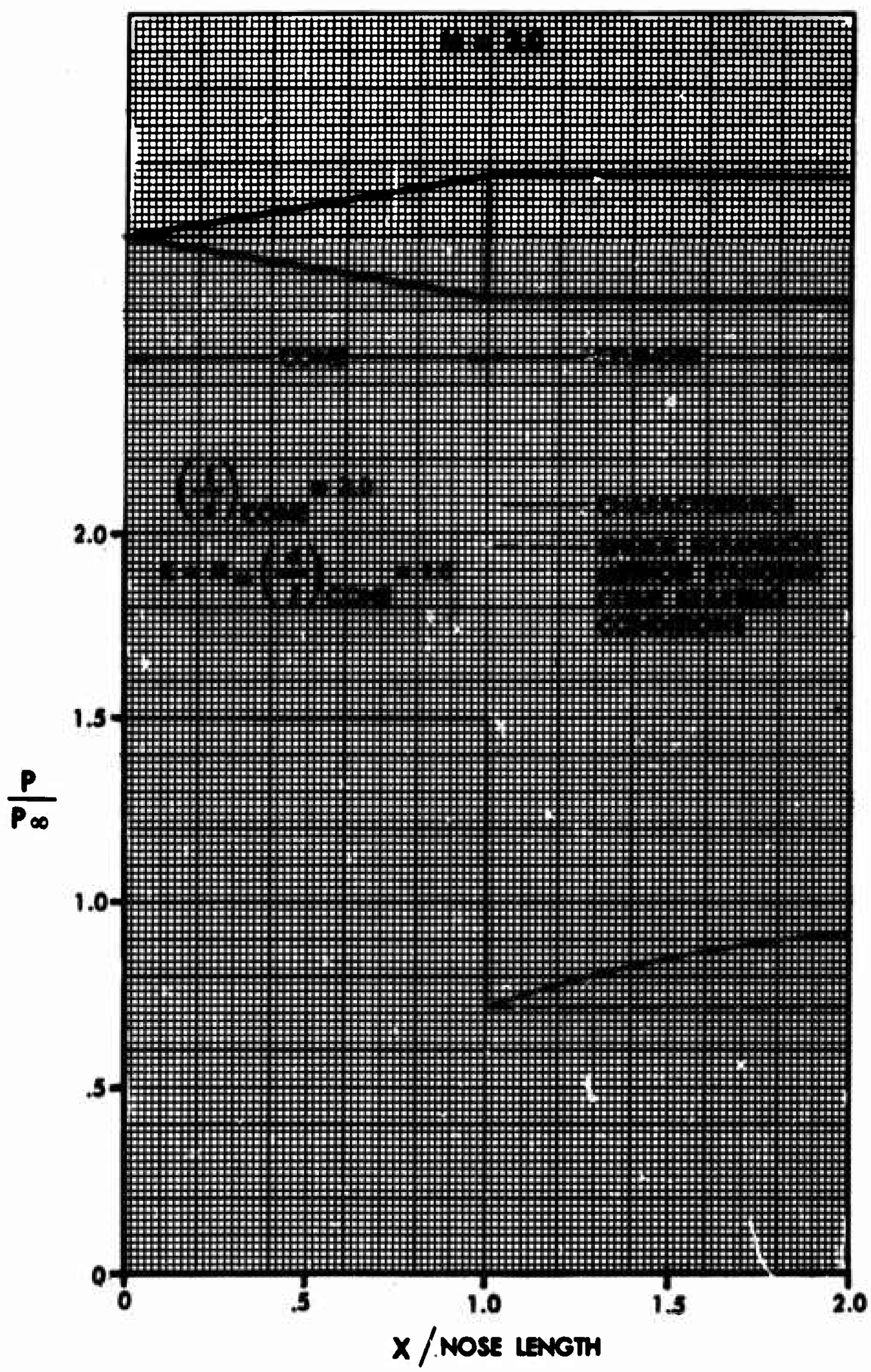


Figure A-23. Comparison of Shock Expansion and Characteristics Solutions for a Cone-Cylinder at M = 3.0

curved surfaces it should be noted that the empirical correlation of separation criteria was based on flat, uncurved sections for the flap itself and the area forward of it. If a curved section is used the boundary conditions on which the correlation were based are not satisfied and the calculated values should be interpreted with this fact in mind.

FREE MOLECULAR FLOW

At very high altitudes the various theoretical approaches based on continuum flow cease to be realistic. The criteria associated with the onset of free molecular flow is the mean free path of the molecules. If the mean free path is everywhere much greater than the characteristic vehicle dimension, the flow may be called free molecular flow.

The process of momentum transfer for this flow model is a function of the accommodation coefficients to be input to the program. These accommodation coefficients are related to the two general modes by which the molecules striking the body may be reflected.

The first model is called "specular" reflection. In this flow model the molecule strikes a smooth flat surface and leaves with its normal velocity component completely reversed and its tangential component unchanged. The accommodation coefficients (f_t and f_n) are zero for specular reflection.

The experimental evidence shows that this model is unrealistic. Thus for practical applications the results obtained with specular reflection should only be used for comparison purposes.

The surface roughness for standard surfaces on actual configurations is not "smooth" in the sense required for specular reflection. The second model notes this fact and assumes the molecules which strike the surface are trapped by the surface and then re-emitted. Any such reflection process which is not specular is called a "diffuse" reflection. For a completely diffuse reflection the accommodation coefficients (f_t, f_n) are equal to 1.0. Most of the experimental data obtained for f_t is in the area of 0.8 to 1.0 and it is generally assumed that f_n is also close to one.

The general assumptions made when calculating the free molecular flow for general shapes are: (1) completely diffuse reflection exists, and (2) constant temperature over a given vehicle section is assumed.

DELTA WING EMPIRICAL

A detailed explanation of this force calculation method appears elsewhere in this report. As shown earlier, this method was derived from experimental data of 60 to 75 degrees sweep deltas at Mach numbers of 6.85 and 9.6. Pressure coefficients calculated by this method are compared with other calculation methods over a wide Mach number range in Figures A-1 through A-6. It should be noted that at a Mach number of 20 for the low to moderate angles of attack the method approximated Newtonian flow due to the high values of M sin δ.

APPENDIX B

SAMPLE PROBLEM

This appendix contains a rather detailed sample problem, complete with a listing of all the input cards, the printed output obtained, and the graphics output generated by the SC-4020 options in the program. This sample problem has been designed to illustrate many of the features and capabilities of the program. A very careful study of this sample problem will help to clarify many of the program operational concepts presented in this report.

This sample problem illustrates certain concepts involved in the solution of a typical problem, the use of the various program options (as controlled by key input flags), and the different types of printed and graphical output produced by the program. However, the amount of output data shown in this problem should not be construed as being typical. In this sample it was necessary to sererely limit the use of the program print options so as to keep the number of pages to be reproduced in this report to a reasonable quantity. In most actual applications the printout would be greatly expanded. The use of expanded printout would be helpful, not only from the standpoint of data analysis, but as trouble shooting information in the case of a run failure or bad data because of erroneous input information.

This sample problem involves the analysis of a typical high L/D reentry vehicle. All input geometry information was obtained from the drawing shown on page B-3. This drawing was made on 20" x 40" grid paper. The first step in loading the geometry data involved the division of the shape into a number of components (identified by the letters A through EV). The illustration given on page B-5 gives a tabulation of each vehicle section, the geometry generation technique used, and the pressure calculation method selected for each component. The free-hand sketches shown on page B-6 were prepared as an aid in identifying the vehicle sections.

For this problem it was decided to use four program phases. The program activity accomplished in each of the phases is outlined below.

Phase 1 Aerodynamic Force Program (option 1)

Generate the geometry for those sections of the shape using the ellipse and parametric cubic options and store the resulting element data (in Type 3 card format) on the geometry storage tape (Unit 8). Next read in all the rest of the geometry data from the standard input tape (Unit 5) and transfer these data to the geometry storage tape also. When all of the vehicle geometry (including the skin-friction geometry model) has been transferred to Tape 8 we will use the Picture Drawing option to check the results of the geometry generation and input operation.

Phase 2 Picture Drawing Program (option 2)

Draw SC-4020 pictures of both the pressure geometry model and the skin-friction geometry model. In this sample problem we have only drawn two views of each model. In a normal application we would usually draw a number of pictures showing the entire vehicle from several different angles. Frequently each section of the vehicle is drawn enlarged on an individual picture frame so that it may be studied in more detail. In addition, a front view showing the cross-sectional cuts with suitable grid lines will usually be obtained.

Phase 3 Aerodynamic Force Program (option 1)

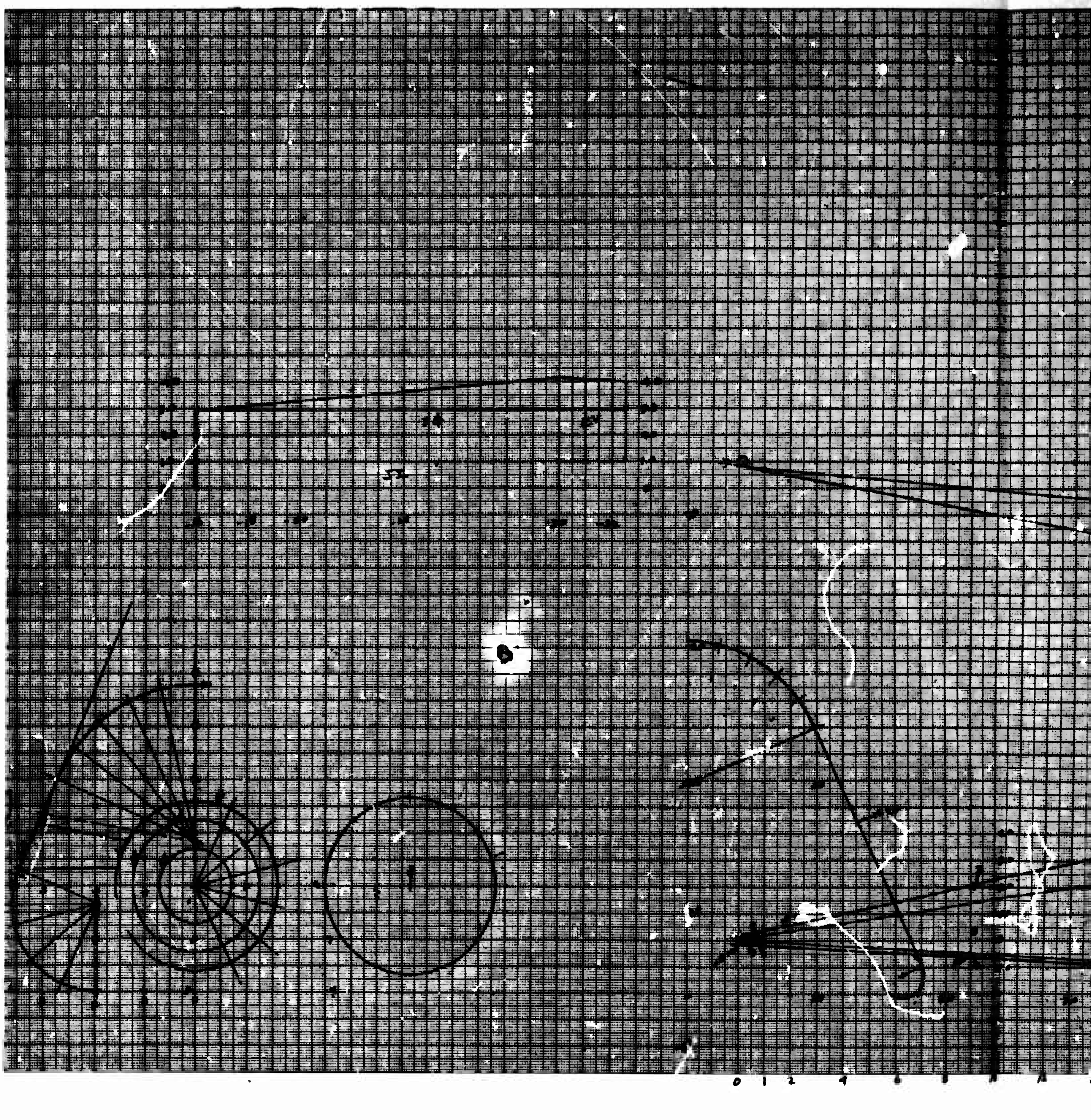
Calculate the aerodynamic characteristics of the vehicle and save the results on the plotting tape. In this problem a component build-up technique was used to assist in the analysis of the output data. Only a few angle of attack points were calculated so as to reduce the amount of output for this report.

Phase 4 Output Data Plotter Program (option 3)

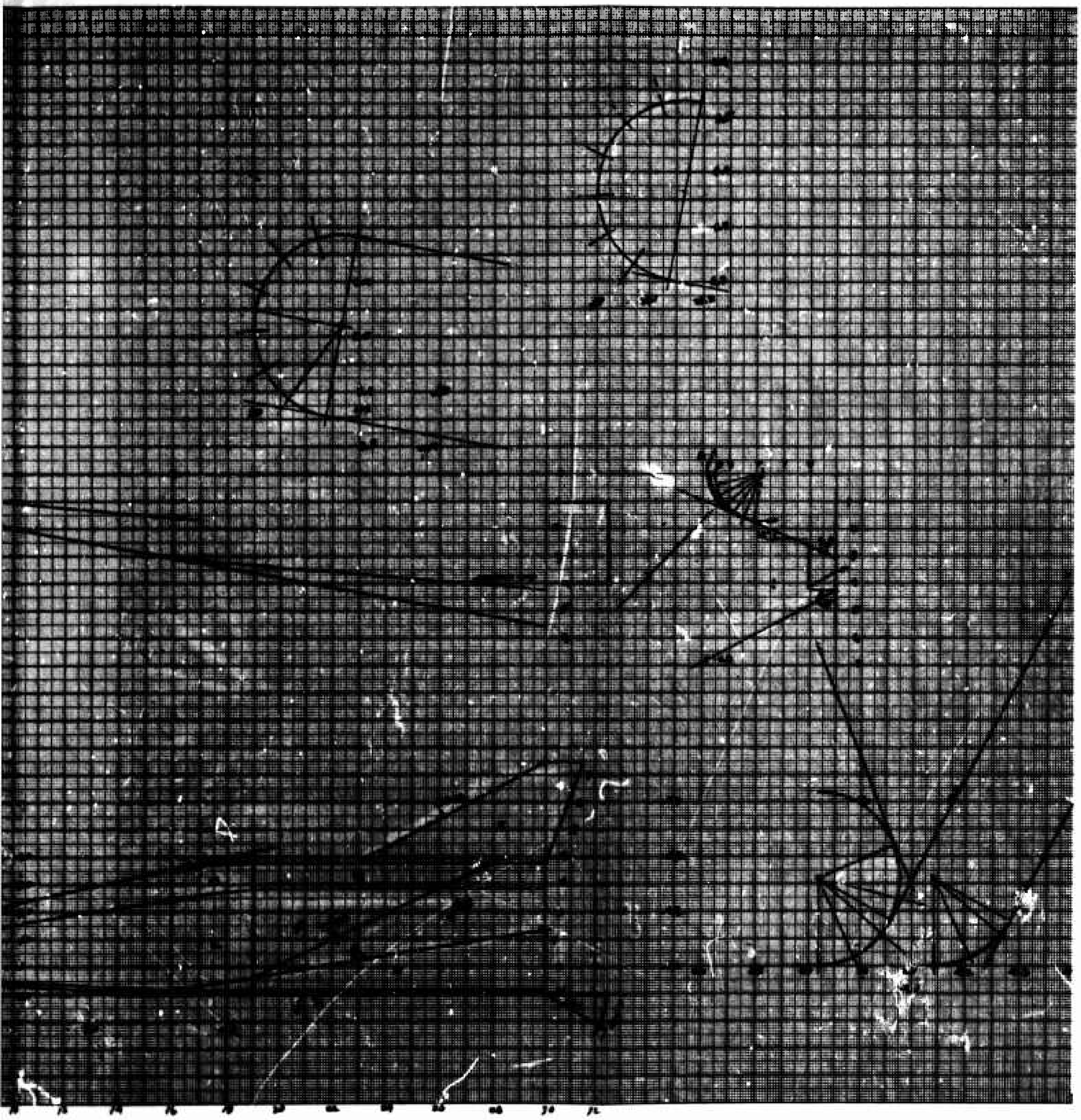
Plot selected output parameters only.

A machine produced listing of all the input cards for this problem is presented on pages B-7 through B-10. This type of listing of all the input cards is usually made before the first machine run on the computer. Errors that may have been overlooked on the original load sheets are usually easily detected when the listing is reviewed. The notes presented at the right side of each page should be of assistance in studying this sample problem.

The output from the Arbitrary-Body Program for this sample problem is given on pages B-11 through B-39. Graphical output obtained from the SC-4020 is presented on pages B-40 through B-47.



A

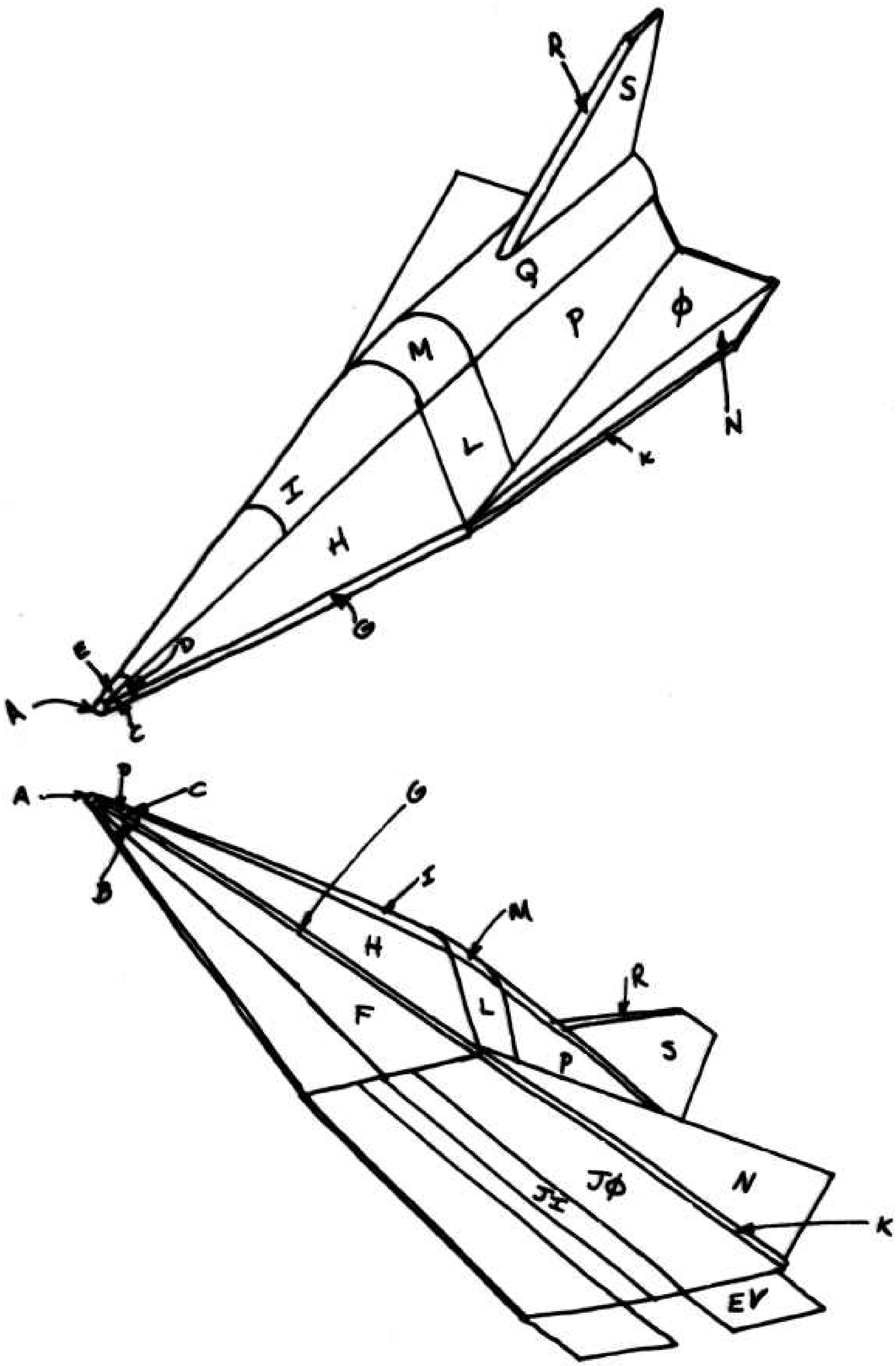


Drawing Used in Loading Sample Problem Vehicle

B

Sample Problem - Component and Pressure Method Selection

Component	Section	Force Methods Compression	Force Methods Expansion
Nose and leading edges	A	Mod. Newt.	$C_p = 0$
	C	"	"
	G	"	"
	K	"	"
Top	I	Tan. Cone	Prandtl-Meyer
	E	"	"
	M	"	"
	Q	"	"
Wedge sides	D	Tan. Cone	Prandtl-Meyer
	H	"	"
	L	"	"
	P	"	"
Bottom ramp	B	Tan. Cone	Prandtl-Meyer
	F	"	"
Inboard aft flat	JI	Shock-Exp.	Shock-Exp.
Outboard aft flat and elevon	JO	Shock-Exp.	Shock-Exp.
	EV	"	"
Aft side fin	N	Tan. Cone	Prandtl-Meyer
Aft upper ramp	O	Tan. Cone	Prandtl-Meyer
Tail leading edge	R	Mod. Newt.	$C_p = 0$
Tail sides	S	Tan. Wedge	Prandtl-Meyer



Sample Problem - Sketch of vehicle components

```
  1  2  1  9
SECTION A  **SPHERICAL NOSE**   ELLIPSE-GENERATED                    01 000 67
0 000                                                               1501   67
SPHERICAL NOSE SECTION **ELLIPSE-GENERATED**                        11     67 A
0.0        0.0    180.0   7  0.0        0.0      0.0      0.0      0      67 A
-0.015     0.0    180.0   7  0.070      0.070    0.0      0.0      0      67 A
-0.055     0.0    180.0   7  0.125      0.125    0.0      0.0      0      67 A
-0.125     0.0    180.0   7  0.162      0.162    0.0      0.0      1      67 A
RETURN TO TYPE 1                                                           67
SECTIONS C,G,K  **LEADING EDGES**                                   00 000 67
0 000                                                               0401   67
-0.125     0.0        -0.162     2-0.125    0.071      -0.145      0      67 C
-0.125     0.125      -0.142     0-0.125    0.127      -0.098      0      67 C
-0.125     0.162       0.00      0-0.125    0.157       0.038      0      67 C
-1.00      0.195      -0.20      1-1.00     [illegible] -0.105     0      67 C
-1.00      0.322      -0.140     0-1.00     0.555      -0.075      0      67 C
-1.00      0.360      -0.035     0-1.00     0.546      -0.037      0      67 C
-1.00      0.195      -0.20      2-1.00     0.294      -0.185      0      67 G
-1.00      0.322      -0.140     0-1.00     0.555      -0.075      0      67 G
-1.00      0.360      -0.035     0-1.00     0.546      -0.037      0      67 G
-16.00     2.970      -1.00      1-16.00    2.989      -0.985      0      67 G
-16.00     3.044      -0.962     0-16.00    3.076      -0.878      0      67 G
-16.00     3.080      -0.839     0-16.00    3.068      -0.778      0      67 G
-16.00     2.920      -1.00      2-16.00    2.989      -0.985      0      67 K
-16.00     3.044      -0.962     0-16.00    3.098      -0.848      0      67 K
-30.00     4.142      -1.00      1-30.00    4.217      -0.985      0      67 K
-30.00     4.266      -0.943     0-30.00    4.321      -0.848      0      67 K
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTION I  **FORWARD TOP**   PARAMETRIC CUBIC INPUT                 00 000 67
0 000                                                               2501   67
FORWARD TOP SECTION   **PARAMETRIC CUBIC INPUT**   2   5            100    67
-1.0       0.292      0.194      2-1.0      0.273      0.200       0      67
-1.0       0.299      0.260      0-1.0      0.191      0.310       0      67
-1.0       0.199      0.346      0-1.0      0.059      0.372       0      67
-1.0       0.00       0.380      0-1.0     -0.059      0.372       0      67
-16.0      1.71       2.15       1-16.0     1.60       2.48        0      67
-16.0      1.39       2.84       0-16.0     1.11       3.15        0      67
-16.0      0.78       3.38       0-16.0     0.40       3.50        0      67
-16.0      0.00       3.55       0-16.0    -0.40       3.50        0      67
0.0        0.185      0.048      1-1.0      0.273      0.200       0      67
-16.0      1.600      2.480      0-17.0     1.688      2.632       0      67
0.0        0.0        0.168      1-1.0      0.0        0.380       0      67
-16.0      0.0        3.550      0-17.0     0.0        3.762       0      67
RETURN TO TYPE 1                                                    1      67
SECTIONS F,M,Q  **TOP**   ELEMENT DATA INPUT                        00 000 67
0 000                                                               0401   67
-0.125     0.100      0.125      2-0.125    0.077      0.140       0      67 F
-0.125     0.056      0.150      0-0.125    0.037      0.156       0      67 F
-0.125     0.019      0.159      0-0.125    0.00       0.162       0      67 F
-1.00      0.279      0.200      1-1.00     0.259      0.260       0      67 F
-1.00      0.191      0.310      0-1.00     0.133      0.348       0      67 F
-1.00      0.059      0.372      0-1.00     0.00       0.380       0      67 F
-16.00     1.60       2.480      2-16.00    1.390      2.810       0      67 M
-16.00     1.10       3.140      0-16.00    0.780      3.360       0      67 M
-16.00     0.40       3.500      0-16.00    0.00       3.550       0      67 M
-17.50     1.320      2.680      1-17.50    1.320      3.070       0      67 M
-17.50     1.080      3.300      0-17.50    0.760      3.550       0      67 M
-17.50     0.400      3.660      0-17.50    0.00       3.710       0      67 M
-19.00     1.480      2.830      1-19.00    1.290      3.180       0      67 M
-19.00     1.090      3.420      0-19.00    0.730      3.620       0      67 M
-19.00     0.380      3.780      0-19.00    0.00       3.800       0      67 M
-19.00     1.480      2.830      2-19.00    1.290      3.180       0      67 Q
-19.00     1.090      3.420      0-19.00    0.730      3.620       0      67 Q
-19.00     0.380      3.780      0-19.00    0.00       3.800       0      67 Q
-30.00     1.480      2.830      1-30.00    1.290      3.180       0      67 Q
-30.00     1.090      3.420      0-30.00    0.730      3.620       0      67 Q
-30.00     0.380      3.780      0-30.00    0.00       3.800       0      67 Q
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTIONS D,H,L,P  **WEDGE SIDES**                                   00 000 67
0 000                                                               0401   67
-0.125     0.157      0.038      2-0.125    0.136      0.084       0      67 D
-0.125     0.180      0.176      0-1.00     0.344      0.032       1      67 D
-1.00      0.309      0.117      0-1.00     0.273      0.200       0      67 D
-1.00      0.346      0.072      2-1.00     0.321      0.087       0      67 H
-1.00      0.298      0.143      0-1.00     0.273      0.200       0      67 H
-9.00      1.805     -0.490      1-9.00     1.535      0.202       0      67 H
-9.00      1.262      0.80       0-9.00     0.960      1.390       0      67 H
-16.00     3.068     -0.778      1-16.00    2.60       0.260       0      67 H
-16.00     2.10       1.360      0-16.00    1.60       2.480       0      67 H
-16.00     3.068     -0.778      2-16.00    2.60       0.260       0      67 L
-16.00     2.100      1.360      0-16.00    1.60       2.480       0      67 L
-17.50     2.940     -0.640      1-17.50    2.47       0.460       0      67 L
-17.50     1.990      1.570      0-17.50    1.32       2.680       0      67 L
-19.00     2.84      -0.40       1-19.00    2.385      0.675       0      67 L
-19.00     1.990      1.750      0-19.00    1.48       2.830       0      67 L
-19.00     2.840     -0.40       2-19.00    1.480      2.830       0      67 P
-30.00     2.10       1.34       1-30.00    1.480      2.830       0      67 P
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTION N   **AFT SIDE FIN**                                        00 000 67
0 000                                                               0401   67
-16.00     3.098     -0.848      2-16.00    3.098     -0.848       0      67 N
-30.00     4.321     -0.848      1-30.00    5.580      1.340       0      67 N
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTION O   **AFT UPPER RAMP**                                      00 000 67
0 000                                                               0401   67
-16.00     3.098     -0.848      2-16.00    3.098     -0.848       0      67 O
-30.00     5.58       1.940      1-30.00    2.100      1.340       0      67 O
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTION R   **TAIL LEADING EDGE**                                   00 000 67
0 000                                                               0401   67
-23.166    0.166      3.800      2-23.084   0.144      3.800       0      67 R
-23.023    0.084      3.800      0-23.000   0.00       3.800       0      67 R
-30.166    0.166      7.500      1-30.084   0.144      7.500       0      67 R
-30.023    0.084      7.500      0-30.000   0.00       7.500       0      67 R
-1.0000000 0.0000000 0.00000002-1.0000000 0.0000001 0.00000000     Z
-1.0000001 0.0000000 0.00000001-1.0000001 0.0000001 0.00000003     Z
RETURN TO TYPE 1                                                    1      67
SECTION S **VERTICAL TAIL SIDES**                                   00 000 67
0 000                                                               0401   67
-23.166    0.166      3.600      2-30.166   0.166      7.500       0      67 S  3AERO1200
```

Put ellipse generated nose data on tape 8

Transfer leading edge data from tape 5 to tape 8

— 1st STATUS=3

Parametric cubic data on tape 8

Tape 5 data to tape 8

— 2nd STATUS=3

Tape 5 data to tape 8

— 3rd STATUS=3

Tape 5 to tape 8

— 4th STATUS=3

Tape 5 to tape 8

— 5th STATUS=3

Tape 5 to tape 8

— 6th STATUS=3

Tape 5 to tape 8

```
-30.000   0.166   3.800   1-31.500   0.166   7.300   0        67
[illegible]
RETURN TO TYPE 1
```

—7th STATUS = 3

```
SECTIONS B.F  **BOTTOM RAMP**                                  1 00.000  67
0.000                                                           0401      67
-0.125    0.00    -0.162   2-0.125    0.00    -0.162    0       67 B
[illegible]
-16.00    0.00    -1.00    1-16.00    2.95    -1.00     0       67 F
[illegible]
RETURN TO TYPE 1
```

Tape 5 to tape 8

—8th STATUS = 3

```
SECTION JI  **INBOARD AFT FLAT**                               1 00.000  67
0.000                                                           0401      67
-15.90    0.00    -0.99466  2-15.90   1.00    -0.99466   0       67JI
-16.00    0.00    -1.00     1-16.00   1.00    -1.00      0       67JI
-30.00    0.00    -1.00     1-30.00   1.00    -1.00      0       67JI
[illegible]
RETURN TO TYPE 1
```

Tape 5 to tape 8

—9th STATUS = 3

```
SECTIONS JO.FV  **OUTBOARD AFT FLAT AND ELEVON**                1 00.000  67
0.010                                                           0401      67
-15.90    2.920   -0.99466  2-16.00   2.970   -1.00      0       67JO
[illegible]
-30.00    4.167   -1.00     0-15.90   [illegible]  -0.99466  1  67JO
[illegible]
                          -0.99466
[illegible]
                                                        -0.99466
[illegible]
RETURN TO TYPE 1
```

Tape 5 to tape 8

—10th (and last) STATUS = 3

```
BODY SURFACES FOR SKIN FRICTION                                 1 00.000  67
0.000                                                           0401      67
-0.125    0.00    -0.162   2-16.00    2.95    -1.00      0       67SF
[illegible]
RETURN TO TYPE 1
```

Skin-friction geometry model (Tape 5 to tape 8)

—STATUS = 3

```
VERTICAL TAIL SURFACE FOR SKIN FRICTION                         1 00.000  67
0.010                                                           0401      67
-30.166   0.166   7.200    2-31.50    0.166   7.300      0       67SF
[illegible]
RETURN TO TYPE 1
```

Vertical tail skin-friction geometry (tape 5 to tape 8);

STATUS = 3

```
BODY SURFACES FOR INDUCED PRESSURES                             1 00.000  67
0.000                                                           0401      67
-0.125    0.00    -0.162   2-16.00    2.95    -1.00      0       67SF
[illegible]
-16.00    3.048   -0.848   1-30.00    4.980   1.940      5       67SF
RETURN TO TYPE 1
```

Skin-friction geometry model (for induced pressure calculations) Tape 5 to tape 8

—STATUS = 3

```
VERTICAL TAIL SURFACE FOR INDUCED PRESSURES                     1 00.000  67
0.010                                                           0401      67
-30.166   0.166   7.200    2-31.50    0.166   7.300      0       67SF
[illegible]                                                      5       67SF
RETURN TO TYPE 1                                                 1       67
********   PHASE TERMINATION CARD  ******************
INVISCID GEOMETRY **TYPICAL HIGH L/D VEHICLE**                             67  STPIC
0 0 1 1.0   1.0   1.0   18.0  0.0  1.0                           1010      67  STPIC
-35.0  25.0   -20.0   0 1 0 0 0 0  0 40   0 0   0 0   0 0        0         67  STPIC
-12.0      20.0     -15.0       17.0                             1         67  STPIC
      TYPICAL HIGH L/D VEHICLE        -35, 25, -20                         67  STPIC
-35.0  -25.0   10.0   0 1 0 0 0 0  0 40   0 0   0 0   0 0        1         67  STPIC
-15.0      15.0     -15.0       15.0                             1         67  STPIC
      TYPICAL HIGH L/D VEHICLE        -35, -25, 10                         67  STPIC
VISCOUS GEOMETRY **TYPICAL HIGH L/D VEHICLE**                              67  STPIC
1 0 1 1.0   1.0   1.0   18.0  0.0  1.0                           211       67  STPIC
-35.0  25.0   -20.0   0 1 0 0 0 0  0 40   0 0   0 0   0 0        0         67  STPIC
-12.0      20.0     -15.0       17.0                             1         67  STPIC
TYPICAL HIGH L/D VEHICLE VISCOUS GEOMETRY    -35, 25, -20                  67  STPIC 2400
```

Vertical tail geometry (for induced pressures)

—STATUS = 3

Graphics

Draw pictures

```
-35.0  -25.0  10.0   0 1 0 0 0 0  0 48     0  0   0  0  0 0 1          67
-15.0        15.0        -15.0        15.0                   1          67
TYPICAL HIGH L/D VEHICLE VISCOUS GEOMETRY     -35, -25, 10             67
************  PHASE TERMINATION CARD  ***************
```

Start of Pressure Calculations

```
SECTIONS A,C,G,K  **NOSE AND LEADING EDGES**                 11 000   67
1 000                                                        0200     67
SECTIONS  A,C,G,K  **NOSE AND LEADING EDGES**                0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   1 1000                      67
7.0   0.0   2.0   0.0   1.0   1.0   1.0   1 1000                      67
10.0  0.0   2.0   0.0   1.0   1.0   1.0   1 1200                      67
12.0  0.0   2.0   0.0   1.0   1.0   1.0   1 1010                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   1 1000                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   1 1000      10.0            67
SECTIONS   I,F,M,Q  **TOP**                                  10 000   67
0 000                                                        0200     67
SECTIONS  F,I,M,Q  **TOP**                                   0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
7.0   0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
10.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3200                      67
12.8  0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3000      10.0            67
```

Sections A,C,G,K,I,F,M,Q

```
INVISCID LEAD. EDGES AND TOP                                 20 000   67
```

Summation

```
SECTIONS D,H,L,P  **WEDGE SIDES**                            10 000   67
0 000                                                        0200     67
SECTIONS D,H,L,P  **WEDGE SIDES**                            0        67
19.0845   200000.0  152.0                0  0    00          0 61 0   67
-18.60    0.00       1.00       8.30     30.00                        67
```

Sections D,H,L,P

```
INVISCID LEAD. EDGES, TOP, SIDES                             20 000   67
```

Summation

```
SECTION  N  **AFT SIDE FIN**                                 10 000   67
0 000                                                        0200     67
SECTION  N  **AFT SIDE FIN**                                 0        67
19.0845   200000.0  152.0                0  0    00          0 61 0   67
-18.60    0.00       1.00       8.30     30.00                        67
```

Section N

```
INVISCID  L.E., TOP, SIDES, SIDE FIN                         20 000   67
```

Summation

```
SECTION  O  **AFT UPPER RAMP**                               10 000   67
0 000                                                        0200     67
SECTION . O  **AFT UPPER RAMP**                              0        67
19.0845   200000.0  152.0                0  0    00          0 61 0   67
-18.60    0.00       1.00       8.30     30.00                        67
```

Section O

```
INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP              20 000   67
```

Summation

```
SECTION R  **VERTICAL FIN LEADING EDGE**                     10 000   67
0 000                                                        0200     67
SECTION R  **VERTICAL FIN LEADING EDGE**                     0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   0.314 1 1000                      67
7.0   0.0   2.0   0.0   1.0   1.0   0.167 1 1000                      67
10.0  0.0   2.0   0.0   1.0   1.0   0.036 1 1200                      67
12.0  0.0   2.0   0.0   1.0   1.0   0.017 1 1000                      67
15.0  0.0   2.0   0.0   1.0   1.0   0.0   1 1000                      67
15.0  0.0   2.0   0.0   1.0   1.0   0.0   1 1000      10.0            67
```

Section R

```
INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP, TAIL L.E.   20 000   67
```

Summation

```
SECTION S **VERTICAL TAIL SIDES**                            10 000   67
0 000                                                        0200     67
SECTION S **VERTICAL TAIL SIDES**                            0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   0.690 3 3000                      67
7.0   0.0   2.0   0.0   1.0   1.0   0.310 3 3000                      67
10.0  0.0   2.0   0.0   1.0   1.0   0.075 3 3200                      67
12.0  0.0   2.0   0.0   1.0   1.0   0.041 3 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   0.011 3 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   0.011 3 3000      10.0            67
```

Section S

```
INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP, TAIL        20 000   67
```

Summation

```
SECTIONS B,F  **BOTTOM RAMP**                                10 000   67
0 000                                                        0200     67
SECTIONS B,F **BOTTOM RAMP**                                 0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
7.0   0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
10.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3200                      67
12.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3000                      67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   5 3000      10.0            67
```

Sections B,F

```
INVISCID  ALL UPPER SURFACES, TAIL, RAMP                     20 000   67
```

Summation

```
SECTION  JI  *AFT INBOARD FLAT**                             10 000   67
0 000                                                        0200     67
SECTION JI **AFT INBOARD FLAT**                              0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3                 67
7.0   0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3                 67
10.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7200  5 3                 67
12.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3                 67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3                 67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 310.0             67
```

Section JI

```
INVISCID  ALL UPPER SURFACES, TAIL, RAMP, INBOARD FLAT       20 000   67
```

Summation

```
SECTIONS  JO,EV  **OUTBOARD AFT FLAT AND ELEVON**            10 000   67
0 010                                    5.99 0.00           0210     67
SECTIONS  JO,EV  **OUTBOARD AFT FLAT AND ELEVON**            0        67
19.0845   200000.0  152.0                0  0    00          0 60 0   67
-18.60    0.00       1.00       8.30     30.00                        67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3 0.0 9999.       67
7.0   0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3 0.0 9999.       67
10.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7200  5 3 0.0 9999.       67
12.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3 0.0 9999.       67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3 0.0 9999.       67
15.0  0.0   2.0   0.0   1.0   1.0   1.0   9 7000  5 3 10.09999.       67
```

Sections JO,EV

```
TOTAL INVISCID DATA                                          20 000   67
```

Summation

Skin-Friction Calculations

```
LAMINAR SKIN FRICTION  **BODY SURFACES**                     10 000   67
1 010                                                        0220     67
LAMINAR SKIN FRICTION  **BODY SURFACES***                    0        67
19.0845   200000.0  152.0                0  0    00          0 60 9   67
-18.60    0.00       1.00       8.30     30.00                        67
 112103111223.7063  16.021   0.00        0.00         1.0             67
 212103000014.1002  14.00    16.0210.718 1.00         1.0             67
 312103000043.3696  16.50    11.50 0.00  1.00         1.0             67
 412103000017.7211  14.00    0.00        1.00         1.0             67
 512103000018.2817  16.644   0.00        1.00         1.0             67
 612103000026.5187  14.00    16.6441.00  1.00         1.0             67
 712103000028.3335  16.00    0.00        1.00         1.0             67
 812103000038.8777  14.00    16.00 1.00  1.00         1.0             67
 912103000024.6557  14.174   0.00        1.00         1.0             67
5.0   0.0   2.0   0.0   1.0   1.0   1.0   1 1000                      67
```

```
7.0   0.0   2.0   0.0    1.0  1.0  1.0  1 1000                              67   12AERO3610
10.0  0.0   2.0   0.0    1.0  1.0  1.0  1 1200                              67   12AERO3620
12.0  0.0   2.0   0.0    1.0  1.0  1.0  1 1010                              67   12AERO3630
15.0  0.0   2.0   0.0    1.0  1.0  1.0  1 1000                              67   12AERO3640
15.0  0.0   2.0   0.0    1.0  1.0  1.0  1 1000         10.0                 67   12AERO3650
INVISCID PLUS BODY SURFACES SKIN FRICTION                          20 000  67    1AERO3660   Summation
LAMINAR SKIN FRICTION   **VERTICAL TAIL**                          10 000  67    1AERO3670
0 010                                                              0220    67    2AERO3680
LAMINAR SKIN FRICTION   **VERTICAL TAIL**                          0       67    8AERO3690
19.0845    200000.0   152.0                      0   0     00      0 60 1  67    9AERO3700
-18.60      0.00        1.00        8.30        30.00                      67   10AERO3710
 11210300015.1109   7.00      0.00              0.314            1.0       67   11AERO3720
5.0   0.0   2.0   0.0    1.0  1.0  0.690  1 1000                            67   12AERO3730
7.0   0.0   2.0   0.0    1.0  1.0  0.310  1 1000                            67   12AERO3740
10.0  0.0   2.0   0.0    1.0  1.0  0.075  1 1200                            67   12AERO3750
12.0  0.0   2.0   0.0    1.0  1.0  0.041  1 1000                            67   12AERO3760
15.0  0.0   2.0   0.0    1.0  1.0  0.011  1 1000                            67   12AERO3770
15.0  0.0   2.0   0.0    1.0  1.0  0.011  1 1000       10.0                 67   12AERO3780
INVISCID PLUS LAMINAR SKIN FRICTION                                20 000  67    1AERO3790   Summation
INDUCED PRESSURES   **BODY SURFACES**                              10 000  67    1AERO3800   Induced pressure
0 010                                                              0220    67    2AERO3810   Calculations
INDUCED PRESSURES   ***BODY SURFACES**                             0       67    8AERO3820
19.0845    200000.0   152.0                      0   0     00      0 60 9  67    9AERO3840
-18.60      0.00        1.00        8.30        30.00                      67   10AERO3840
 11210300073.7063   16.021     0.00             0.00             1.0       67   11AERO3850
 21210300014.1002   14.00      16.0210.718      1.00             1.0       67   11AERO3860
 31210300043.3696   16.50      11.50 0.00       1.00             1.0       67   11AERO3870
 41210300017.7211   14.00      0.00             1.00             1.0       67   11AERO3880
 51210300018.2817   16.444     0.00             1.00             1.0       67   11AERO3890
 61210300026.5187   14.00      16.0441.00       1.00             1.0       67   11AERO3900
 71210300028.3935   16.00      0.00             1.00             1.0       67   11AERO3910
 81210300038.8777   14.00      16.00 1.00       1.00             1.0       67   11AERO3920
 91210300024.6557   14.174     0.00             1.00             1.0       67   11AERO3930
5.0   0.0   2.0   0.0    1.0  1.0  1.0  1710000                             67   12AERO3940
7.0   0.0   2.0   0.0    1.0  1.0  1.0  1710000                             67   12AERO3950
10.0  0.0   2.0   0.0    1.0  1.0  1.0  1712200                             67   12AERO3960
12.0  0.0   2.0   0.0    1.0  1.0  1.0  1710000                             67   12AERO3970
15.0  0.0   2.0   0.0    1.0  1.0  1.0  1712000                             67   12AERO3980
15.0  0.0   2.0   0.0    1.0  1.0  1.0  1710000    10.0                     67   12AERO3990
INVISCID - LAM. S.F. - BODY SURFACES INDUCED PRESSURES             20 000  67    1AERO4000   Summation
INDUCED PRESSURES **VERTICAL TAIL**                                10 000  67    1AERO4010
0 010                                                              0220    67    2AERO4020
INDUCED PRESSURES   **VERTICAL TAIL**                              0       67    8AERO4030
19.0845    200000.0   152.0                      0   0     00      0 60 1  67    9AERO4040
-18.60      0.00        1.00        8.30        33.00                      67   10AERO4050
 11210300015.1109   7.00      0.00              0.314            1.0       67   11AERO4060
5.0   0.0   2.0   0.0    1.0  1.0  0.6901710000                             67   12AERO4070
7.0   0.0   2.0   0.0    1.0  1.0  0.3101710000                             67   12AERO4080
10.0  0.0   2.0   0.0    1.0  1.0  0.0751712200                             67   12AERO4090
12.0  0.0   2.0   0.0    1.0  1.0  0.0411710000                             67   12AERO4100
15.0  0.0   2.0   0.0    1.0  1.0  0.0111712000                             67   12AERO4110
15.0  0.0   2.0   0.0    1.0  1.0  0.0111710000    10.0                     67   12AERO4120
INVISCID PLUS LAMINAR SKIN FRICTION PLUS INDUCED PRESSURES 20 100  67        1AERO4130   Final Summation
*************** PHASE TERMINATION CARD ***************                       99AERO4140
    0                                                                       41PLOT4150
                     NORMAL FORCE COEFFICIENT                               42PLOT4160   Plot Output
                  ANGLE OF ATTACK  -  DEGREES                               43PLOT4170   Data
0.0        25.0        0.0       0.5       1.0       0.02                   44PLOT4180
 1  6 1  -5  -5  +5 +5   0   1  1   1 30  1  0 1  4 3  1.0   0              47PLOT4190
            TYPICAL HIGH L/D VEHICLE  * CN VS ALPHA *                       48PLOT4200
                     AXIAL FORCE COEFFICIENT                                41PLOT4210
                  ANGLE OF ATTACK  -  DEGREES                               42PLOT4220
0.0        25.0        0.0       0.05      1.0       0.002                  43PLOT4230
 1  4 1  -5  -4  +5 +5   0   1  1   1 30  1  0 1  4 4  1.0   0              47PLOT4240
            TYPICAL HIGH L/D VEHICLE  * CA VS ALPHA *                       48PLOT4250
                     LIFT TO DRAG RATIO                                     41PLOT4260
                  ANGLE OF ATTACK  -  DEGREES                               42PLOT4270
0.0        25.0        0.0       5.0       1.0       0.2                    44PLOT4280
 1  8 1  -5  -5   5  5   0   1  1   1 30  1  0 1  4 3  1 0   0              47PLOT4290
            TYPICAL HIGH L/D VEHICLE  * L/D VS ALPHA *                      48PLOT4300
                     NORMAL FORCE COEFFICIENT                               41PLOT4310
                  PITCHING MOMENT COEFFICIENT                               42PLOT4320
0.02       -0.04       0.0       0.5       0.002     0.02                   44PLOT4330
 4  6 1  -5  -5   5  5   0   1  1   1 30  1  0 0  5 3  1 0   0              47PLOT4340
            TYPICAL HIGH L/D VEHICLE  * CN VS CM *                          48PLOT4350
************ PHASE TERMINATION CARD ************                            99PLOT4360
```

************* HYPERSONIC ARBITRARY-BODY AERODYNAMIC COMPUTER PROGRAM SYSTEM *************

PROGRAM OPTIONS ARE IN THE FOLLOWING ORDER....

1 AERODYNAMIC FORCE PROGRAM (OPTION 1)

2 PICTURE DRAWING PROGRAM (OPTION 2)

3 AERODYNAMIC FORCE PROGRAM (OPTION 1)

4 OUTPUT DATA PLOTTER PROGRAM (OPTION 3)

ELLIPTICAL GEOMETRY DATA IS BEING GENERATED **********

ANALYTICALLY GENERATED ELEMENT DATA

CASE 67 SPHERICAL NOSE SECTION **ELLIPSE-GENERATED** PAGE 1

X	Y	Z	S	X	Y	Z	S	CASE SECT	SEQ
0.0	0.0	0.0	2	0.0	0.0	0.0	0	67 A 3AERO	1
0.0	0.0	0.0	0	0.0	0.0	0.0		67 A 3AERO	2
0.0	0.0	0.0	0	0.0	0.0	0.0	0	67 A 3AERO	3
0.0	0.0	0.0	0	0.0	0.0	0.0	0	67 A 3AERO	4
-0.0150	0.0	-0.07001		-0.0150	0.0304	-0.06310		67 A 3AERO	5
-0.0150	0.0547	-0.04360		-0.0150	0.0682	-0.01560		67 A 3AERO	6
-0.0150	0.0682	0.01560		-0.0150	0.0547	0.04360		67 A 3AERO	7
-0.0150	0.0304	0.06310		-0.0150	0.0000	0.07000		67 A 3AERO	8
-0.0550	0.0	-0.12501		-0.0550	0.0542	-0.11260		67 A 3AERO	9
-0.0550	0.0977	-0.07790		-0.0550	0.1219	-0.02780		67 A 3AERO	10
-0.0550	0.1219	0.02780		-0.0550	0.0977	0.07790		67 A 3AERO	11
-0.0550	0.0542	0.11260		-0.0550	0.0000	0.12500		67 A 3AERO	12
-0.1250	0.0	-0.16201		-0.1250	0.0703	-0.14600		67 A 3AERO	13
-0.1250	0.1267	-0.10100		-0.1250	0.1579	-0.03600		67 A 3AERO	14
-0.1250	0.1579	0.03600		-0.1250	0.1267	0.10100		67 A 3AERO	15
-0.1250	0.0703	0.14600		-0.1250	0.0000	0.16200		67 A 3AERO	16

SECTION = C TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = G TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = K TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = K TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

PARAMETRIC CUBIC GEOMETRY DATA IS BEING GENERATED *******

SECTION = E TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = M TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = Q TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = U TOTAL AREA OF INPUT ELEMENTS = 0.0 TOTAL NUMBER OF ELEMENTS = 0
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

```
SECTION = D    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = H    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = L    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = P    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = P    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********


SECTION = N    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = N    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********


SECTION = O    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = O    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********


SECTION = R    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = R    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********


SECTION = S    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = S    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********


SECTION = B    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = F    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********

SECTION = F    TOTAL AREA OF INPUT ELEMENTS =       0.0      TOTAL NUMBER OF ELEMENTS =    0
             TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                   *********                   *********                 *********
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SECTION =JI   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =JI   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********



SECTION =JJ   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =EV   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********



SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********

SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********



SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =      0.0       TOTAL NUMBER OF ELEMENTS =    0
            TOTAL VOLUME OF INPUT ELEMENTS =      0.0

                 *********                  *********                  *********
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```
SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********

SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********




SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =        0.0        TOTAL NUMBER OF ELEMENTS =     0
              TOTAL VOLUME OF INPUT ELEMENTS =        0.0

                    *********                 *********                   *********




******** MAIN PROGRAM NOW HAS CONTROL OF SYSTEM ********

***** GRAPHIC OPTION HAS CONTROL *****

          PICTURE DRAWING PROGRAM WILL BE EXECUTED
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PICTURE DRAWING PROGRAM     PICTURE NUMBER    1
          TOTAL AREA OF INPUT ELEMENTS   =         0.0631      TOTAL NUMBER OF ELEMENTS =   21
         TOTAL VOLUME OF INPUT ELEMENTS  =        0.003
          TOTAL AREA OF INPUT ELEMENTS   =         0.3372      TOTAL NUMBER OF ELEMENTS =   26
         TOTAL VOLUME OF INPUT ELEMENTS  =        0.047
          TOTAL AREA OF INPUT ELEMENTS   =         5.1893      TOTAL NUMBER OF ELEMENTS =   31
         TOTAL VOLUME OF INPUT ELEMENTS  =        5.762
          TOTAL AREA OF INPUT ELEMENTS   =         8.6854      TOTAL NUMBER OF ELEMENTS =   34
         TOTAL VOLUME OF INPUT ELEMENTS  =       13.547
          TOTAL AREA OF INPUT ELEMENTS   =         8.6854      TOTAL NUMBER OF ELEMENTS =   35
         TOTAL VOLUME OF INPUT ELEMENTS  =       13.547
          TOTAL AREA OF INPUT ELEMENTS   =        26.7653      TOTAL NUMBER OF ELEMENTS =   45
         TOTAL VOLUME OF INPUT ELEMENTS  =       20.749
          TOTAL AREA OF INPUT ELEMENTS   =        26.9671      TOTAL NUMBER OF ELEMENTS =   50
         TOTAL VOLUME OF INPUT ELEMENTS  =       20.762
          TOTAL AREA OF INPUT ELEMENTS   =        32.8279      TOTAL NUMBER OF ELEMENTS =   60
         TOTAL VOLUME OF INPUT ELEMENTS  =       24.123
          TOTAL AREA OF INPUT ELEMENTS   =        53.4858      TOTAL NUMBER OF ELEMENTS =   65
         TOTAL VOLUME OF INPUT ELEMENTS  =       35.472
          TOTAL AREA OF INPUT ELEMENTS   =        53.4858      TOTAL NUMBER OF ELEMENTS =   66
         TOTAL VOLUME OF INPUT ELEMENTS  =       35.472
          TOTAL AREA OF INPUT ELEMENTS   =        53.6141      TOTAL NUMBER OF ELEMENTS =   68
         TOTAL VOLUME OF INPUT ELEMENTS  =       35.498
          TOTAL AREA OF INPUT ELEMENTS   =        81.8193      TOTAL NUMBER OF ELEMENTS =   74
         TOTAL VOLUME OF INPUT ELEMENTS  =       77.018
          TOTAL AREA OF INPUT ELEMENTS   =        92.5454      TOTAL NUMBER OF ELEMENTS =   80
         TOTAL VOLUME OF INPUT ELEMENTS  =       99.043
          TOTAL AREA OF INPUT ELEMENTS   =       120.6970      TOTAL NUMBER OF ELEMENTS =   81
         TOTAL VOLUME OF INPUT ELEMENTS  =      150.905
          TOTAL AREA OF INPUT ELEMENTS   =       120.6970      TOTAL NUMBER OF ELEMENTS =   82
         TOTAL VOLUME OF INPUT ELEMENTS  =      150.905
          TOTAL AREA OF INPUT ELEMENTS   =       138.4181      TOTAL NUMBER OF ELEMENTS =   83
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.269
          TOTAL AREA OF INPUT ELEMENTS   =       138.4181      TOTAL NUMBER OF ELEMENTS =   84
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.269
          TOTAL AREA OF INPUT ELEMENTS   =       163.0738      TOTAL NUMBER OF ELEMENTS =   85
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.269
          TOTAL AREA OF INPUT ELEMENTS   =       163.0738      TOTAL NUMBER OF ELEMENTS =   86
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.269
          TOTAL AREA OF INPUT ELEMENTS   =       164.6200      TOTAL NUMBER OF ELEMENTS =   89
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.345
          TOTAL AREA OF INPUT ELEMENTS   =       164.6200      TOTAL NUMBER OF ELEMENTS =   90
         TOTAL VOLUME OF INPUT ELEMENTS  =      217.345
          TOTAL AREA OF INPUT ELEMENTS   =       179.7309      TOTAL NUMBER OF ELEMENTS =   91
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       179.7309      TOTAL NUMBER OF ELEMENTS =   92
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       179.8163      TOTAL NUMBER OF ELEMENTS =   93
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       203.4372      TOTAL NUMBER OF ELEMENTS =   94
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       203.4372      TOTAL NUMBER OF ELEMENTS =   95
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       217.5374      TOTAL NUMBER OF ELEMENTS =   97
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       217.5374      TOTAL NUMBER OF ELEMENTS =   98
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       253.2314      TOTAL NUMBER OF ELEMENTS =  122
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
          TOTAL AREA OF INPUT ELEMENTS   =       260.9070      TOTAL NUMBER OF ELEMENTS =  137
         TOTAL VOLUME OF INPUT ELEMENTS  =      219.854
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PICTURE DRAWING PROGRAM    PICTURE NUMBER    2
        TOTAL AREA OF INPUT ELEMENTS   =        0.0631     TOTAL NUMBER OF ELEMENTS =   21
       TOTAL VOLUME OF INPUT ELEMENTS  =      0.003
        TOTAL AREA OF INPUT ELEMENTS   =        0.3372     TOTAL NUMBER OF ELEMENTS =   26
       TOTAL VOLUME OF INPUT ELEMENTS  =      0.047
        TOTAL AREA OF INPUT ELEMENTS   =        5.1893     TOTAL NUMBER OF ELEMENTS =   31
       TOTAL VOLUME OF INPUT ELEMENTS  =      5.768
        TOTAL AREA OF INPUT ELEMENTS   =        8.6854     TOTAL NUMBER OF ELEMENTS =   34
       TOTAL VOLUME OF INPUT ELEMENTS  =     13.547
        TOTAL AREA OF INPUT ELEMENTS   =        8.6854     TOTAL NUMBER OF ELEMENTS =   35
       TOTAL VOLUME OF INPUT ELEMENTS  =     13.547
        TOTAL AREA OF INPUT ELEMENTS   =       26.7653     TOTAL NUMBER OF ELEMENTS =   45
       TOTAL VOLUME OF INPUT ELEMENTS  =     20.749
        TOTAL AREA OF INPUT ELEMENTS   =       26.9671     TOTAL NUMBER OF ELEMENTS =   50
       TOTAL VOLUME OF INPUT ELEMENTS  =     20.762
        TOTAL AREA OF INPUT ELEMENTS   =       32.8279     TOTAL NUMBER OF ELEMENTS =   60
       TOTAL VOLUME OF INPUT ELEMENTS  =     24.123
        TOTAL AREA OF INPUT ELEMENTS   =       53.4858     TOTAL NUMBER OF ELEMENTS =   65
       TOTAL VOLUME OF INPUT ELEMENTS  =     35.472
        TOTAL AREA OF INPUT ELEMENTS   =       53.4858     TOTAL NUMBER OF ELEMENTS =   66
       TOTAL VOLUME OF INPUT ELEMENTS  =     35.472
        TOTAL AREA OF INPUT ELEMENTS   =       53.6141     TOTAL NUMBER OF ELEMENTS =   68
       TOTAL VOLUME OF INPUT ELEMENTS  =     35.498
        TOTAL AREA OF INPUT ELEMENTS   =       81.8193     TOTAL NUMBER OF ELEMENTS =   74
       TOTAL VOLUME OF INPUT ELEMENTS  =     77.018
        TOTAL AREA OF INPUT ELEMENTS   =       92.5454     TOTAL NUMBER OF ELEMENTS =   80
       TOTAL VOLUME OF INPUT ELEMENTS  =     99.043
        TOTAL AREA OF INPUT ELEMENTS   =      120.6970     TOTAL NUMBER OF ELEMENTS =   81
       TOTAL VOLUME OF INPUT ELEMENTS  =    150.905
        TOTAL AREA OF INPUT ELEMENTS   =      120.6970     TOTAL NUMBER OF ELEMENTS =   82
       TOTAL VOLUME OF INPUT ELEMENTS  =    150.905
        TOTAL AREA OF INPUT ELEMENTS   =      138.4181     TOTAL NUMBER OF ELEMENTS =   83
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.269
        TOTAL AREA OF INPUT ELEMENTS   =      138.4181     TOTAL NUMBER OF ELEMENTS =   84
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.269
        TOTAL AREA OF INPUT ELEMENTS   =      163.0738     TOTAL NUMBER OF ELEMENTS =   85
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.269
        TOTAL AREA OF INPUT ELEMENTS   =      163.0738     TOTAL NUMBER OF ELEMENTS =   86
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.269
        TOTAL AREA OF INPUT ELEMENTS   =      164.6200     TOTAL NUMBER OF ELEMENTS =   89
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.345
        TOTAL AREA OF INPUT ELEMENTS   =      164.6200     TOTAL NUMBER OF ELEMENTS =   90
       TOTAL VOLUME OF INPUT ELEMENTS  =    217.345
        TOTAL AREA OF INPUT ELEMENTS   =      179.7309     TOTAL NUMBER OF ELEMENTS =   91
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      179.7309     TOTAL NUMBER OF ELEMENTS =   92
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      179.8163     TOTAL NUMBER OF ELEMENTS =   93
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      203.4372     TOTAL NUMBER OF ELEMENTS =   94
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      203.4372     TOTAL NUMBER OF ELEMENTS =   95
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      217.5374     TOTAL NUMBER OF ELEMENTS =   97
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      217.5374     TOTAL NUMBER OF ELEMENTS =   98
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      253.2314     TOTAL NUMBER OF ELEMENTS =  122
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854
        TOTAL AREA OF INPUT ELEMENTS   =      260.9070     TOTAL NUMBER OF ELEMENTS =  137
       TOTAL VOLUME OF INPUT ELEMENTS  =    219.854


PICTURE DRAWING PROGRAM    PICTURE NUMBER    3


     QUADRILATERAL CHARACTERISTICS - PICTURE DRAWING PROGRAM

      CASE   67                                                                     PAGE    2

  VISCOUS GEOMETRY   **TYPICAL HIGH L/D VEHICLE**

    INPUT SURFACE ELEMENT DATA

      N   M        X              X              X              X           NX          XCENT          AREA         L
                   Y              Y              Y              Y           NY          YCENT        DELTA V
                   Z              Z              Z              Z           NZ          ZCENT         VOLUME


      1   1   1.78750E 01    2.00000E 00    2.00000E 00    1.78750E 01  0.052714    7.29167E 00    2.34492E 01      1
              0.0            2.95000E 00    0.0            0.0          0.0         9.83333E-01    0.0
              8.38000E-01    0.0            0.0            8.38000E-01 -0.998610    2.79333E-01    0.0
                     TOTAL AREA OF INPUT ELEMENTS   =     23.4482      TOTAL NUMBER OF ELEMENTS =     1
                    TOTAL VOLUME OF INPUT ELEMENTS  =     0.0

      1   1   2.00000E 00   -1.20000E 01   -1.20000E 01    2.00000E 00  0.0        -5.00000E 00    1.40000E 01      2
              1.00000E 00    1.00000E 00    0.0            0.0          0.0         5.00000E-01    0.0
              0.0            0.0            0.0            0.0         -1.000000    0.0            0.0
                     TOTAL AREA OF INPUT ELEMENTS   =     37.4482      TOTAL NUMBER OF ELEMENTS =     2
                    TOTAL VOLUME OF INPUT ELEMENTS  =     0.0

      1   1   2.00000E 00   -1.45000E 01   -1.45000E 01    2.00000E 00  0.0        -6.87624E 00    4.16625E 01      3
              2.95000E 00    4.10000E 00    1.00000E 00    1.00000E 00  0.0         2.28432E 00    0.0
              0.0            0.0            0.0            0.0         -1.000000    0.0            0.0
                     TOTAL AREA OF INPUT ELEMENTS   =     79.1107      TOTAL NUMBER OF ELEMENTS =     3
                    TOTAL VOLUME OF INPUT ELEMENTS  =     0.0

      1   1   2.00000E 00   -1.20000E 01   -1.20000E 01    2.00000E 00  0.075501   -7.33333E 00    1.77211E 01      4
              3.09800E 00    5.58000E 00    4.32100E 00    3.09800E 00  0.864278    4.33799E 00    6.63641E 01
              1.52000E-01    2.34000E 00    1.52000E-01    1.52000E-01 -0.497316    8.81332E-01    6.63641E 01
                     TOTAL AREA OF INPUT ELEMENTS   =     96.8318      TOTAL NUMBER OF ELEMENTS =     4
                    TOTAL VOLUME OF INPUT ELEMENTS  =    66.364

      1   1   1.78750E 01    2.00000E 00    2.00000E 00    1.78750E 01  0.174633    7.56354E 00    1.63537E 01      5
              0.0            0.0            1.60000E 00    1.00000E-01  0.537297    5.37119E-01    4.71955E 00
              1.16200E 00    4.55000E 00    3.48000E 00    1.12500E 00  0.825116    3.00868E 00    7.10836E 01
                     TOTAL AREA OF INPUT ELEMENTS   =    113.1855      TOTAL NUMBER OF ELEMENTS =     5
                    TOTAL VOLUME OF INPUT ELEMENTS  =    71.084
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QUADRILATERAL CHARACTERISTICS - PICTURE DRAWING PROGRAM

   CASE   67                                                                                     PAGE    3

VISCOUS GEOMETRY  **TYPICAL HIGH L/D VEHICLE**

 INPUT SURFACE ELEMENT DATA

   N   M        X              X              X              X            NX         XCENT          AREA          L
                Y              Y              Y              Y            NY         YCENT         DELTA V
                Z              Z              Z              Z            NZ         ZCENT         VOLUME


   1   1   2.00000E 00  -1.20000E 01  -1.20000E 01   2.00000E 00  0.015497  -4.90194E 00   2.58633E 01       6
           0.0           0.0           1.48000E 00   1.60000E 00  0.552133   7.70423E-01   1.10016E 01
           4.55000E 00   4.80000E 00   3.83000E 00   3.48000E 00  0.833612   4.16289E 00   3.20857E 01
                      TOTAL AREA OF INPUT ELEMENTS   =      139.0488       TOTAL NUMBER OF ELEMENTS =     6
                     TOTAL  VOLUME OF INPUT ELEMENTS =     82.085

   1   1   1.78750E 01   2.00000E 00   2.00000E 00   1.78750E 01  0.144915   7.43783E 00   3.01095E 01       7
           1.00000E-01   1.60000E 00   3.09800E 00   1.57000E-01  0.900531   1.58837E 00   4.30678E 01
           1.12600E 00   3.48000E 00   1.52000E-01   1.03800E 00  0.409932   1.56461E 00   1.25153E 02
                      TOTAL AREA OF INPUT ELEMENTS   =      169.1582       TOTAL NUMBER OF ELEMENTS =     7
                     TOTAL  VOLUME OF INPUT ELEMENTS =     125.153

   1   1   2.00000E 00  -1.20000E 01  -1.20000E 01   2.00000E 00 -0.000075  -4.09737E 00   3.68409E 01       8
           1.60000E 00   1.48000E 00   2.10000E 00   3.09800E 00  0.915450   2.10554E 00   7.10113E 01
           3.48000E 00   3.83000E 00   2.34000E 00   1.52000E-01  0.402433   2.36868E 00   1.96164E 02
                      TOTAL AREA OF INPUT ELEMENTS   =      205.9991       TOTAL NUMBER OF ELEMENTS =     8
                     TOTAL  VOLUME OF INPUT ELEMENTS =     196.164

   1   1   2.00000E 00  -1.20000E 01  -1.20000E 01   2.00000E 00  0.154411  -7.33333E 00   2.46557E 01       9
           3.09800E 00   2.10000E 00   5.58000E 00   3.09800E 00  0.0         3.59266E 00   0.0
           1.52000E-01   2.34000E 00   2.34000E 00   1.52000E-01  0.988007   1.61066E 00   1.96164E 02
                      TOTAL AREA OF INPUT ELEMENTS   =      230.6548       TOTAL NUMBER OF ELEMENTS =     9
                     TOTAL  VOLUME OF INPUT ELEMENTS =     196.164

   1   1  -1.21660E 01  -1.3[illegible]00E 01  -1.20000E 01  -5.16599E 00  0.0        -1.02310E 01   1.51108E 01      10
           1.66000E-01   1.66000E-01   1.66000E-01   1.66000E-01  1.000000   1.66000E-01   2.50840E 00
           8.50000E 00   8.50000E 00   4.80000E 00   4.80000E 00  0.0         6.23475E 00   1.98673E 02
                      TOTAL AREA OF INPUT ELEMENTS   =      245.7656       TOTAL NUMBER OF ELEMENTS =    10
                     TOTAL  VOLUME OF INPUT ELEMENTS =     198.673


PICTURE DRAWING PROGRAM      PICTURE NUMBER    4
                              TOTAL AREA OF INPUT ELEMENTS   =      23.4482      TOTAL NUMBER OF ELEMENTS =    1
                            TOTAL VOLUME OF INPUT ELEMENTS   =      0.0
                              TOTAL AREA OF INPUT ELEMENTS   =      37.4482      TOTAL NUMBER OF ELEMENTS =    2
                            TOTAL VOLUME OF INPUT ELEMENTS   =      0.0
                              TOTAL AREA OF INPUT ELEMENTS   =      79.1107      TOTAL NUMBER OF ELEMENTS =    3
                            TOTAL VOLUME OF INPUT ELEMENTS   =      0.0
                              TOTAL AREA OF INPUT ELEMENTS   =      96.8318      TOTAL NUMBER OF ELEMENTS =    4
                            TOTAL VOLUME OF INPUT ELEMENTS   =     66.364
                              TOTAL AREA OF INPUT ELEMENTS   =     113.1855      TOTAL NUMBER OF ELEMENTS =    5
                            TOTAL VOLUME OF INPUT ELEMENTS   =     71.084
                              TOTAL AREA OF INPUT ELEMENTS   =     139.0488      TOTAL NUMBER OF ELEMENTS =    6
                            TOTAL VOLUME OF INPUT ELEMENTS   =     82.085
                              TOTAL AREA OF INPUT ELEMENTS   =     169.1582      TOTAL NUMBER OF ELEMENTS =    7
                            TOTAL VOLUME OF INPUT ELEMENTS   =    125.153
                              TOTAL AREA OF INPUT ELEMENTS   =     205.9991      TOTAL NUMBER OF ELEMENTS =    8
                            TOTAL VOLUME OF INPUT ELEMENTS   =    196.164
                              TOTAL AREA OF INPUT ELEMENTS   =     230.6548      TOTAL NUMBER OF ELEMENTS =    9
                            TOTAL VOLUME OF INPUT ELEMENTS   =    196.164
                              TOTAL AREA OF INPUT ELEMENTS   =     245.7656      TOTAL NUMBER OF ELEMENTS =   10
                            TOTAL VOLUME OF INPUT ELEMENTS   =    198.673




******** MAIN PROGRAM NOW HAS CONTROL OF SYSTEM ********
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SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

INPUT SURFACE ELEMENT DATA

N	M	X	X	X	X	NX	XCENT	AREA	L
		Y	Y	Y	Y	NY	YCENT	DELTA V	
		Z	Z	Z	Z	NZ	ZCENT	VOLUME	
1	1	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976699	-9.99999E-03	1.08938E-03	1
		0.0	0.0	3.04000E-02	0.0	0.047504	1.01333E-02	5.24401E-07	
		0.0	0.0	-6.31000E-02	-7.00000E-02	-0.209292	-4.43667E-02	5.24401E-07	
	2	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976683	-9.99999E-03	1.08845E-03	2
		0.0	0.0	5.47000E-02	3.04000E-02	0.134366	2.83667E-02	4.14863E-06	
		0.0	0.0	-4.36000E-02	-6.31000E-02	-0.167441	-3.55667E-02	4.67303E-06	
	3	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976652	-9.99999E-03	1.08543E-03	3
		0.0	0.0	6.82000E-02	5.47000E-02	0.193471	4.09667E-02	8.60299E-06	
		0.0	0.0	-1.56000E-02	-4.36000E-02	-0.093281	-1.97333E-02	1.32760E-05	
	4	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976656	-9.99999E-03	1.08935E-03	4
		0.0	0.0	6.82000E-02	6.82000E-02	0.214807	4.54667E-02	1.06392E-05	
		0.0	0.0	1.56000E-02	-1.56000E-02	0.0	6.98492E-10	2.39152E-05	
	5	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976662	-9.99999E-03	1.08543E-03	5
		0.0	0.0	5.47000E-02	6.82000E-02	0.193471	4.09667E-02	8.60299E-06	
		0.0	0.0	4.36000E-02	1.56000E-02	0.093281	1.97333E-02	3.25182E-05	
	6	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976683	-9.99999E-03	1.08844E-03	6
		0.0	0.0	3.04000E-02	5.47000E-02	0.134366	2.83667E-02	4.14862E-06	
		0.0	0.0	6.31000E-02	4.36000E-02	0.167441	3.55666E-02	3.66668E-05	
	7	0.0	0.0	-1.50000E-02	-1.50000E-02	0.976699	-9.99999E-03	1.08938E-03	7
		0.0	0.0	0.0	3.04000E-02	0.047504	1.01333E-02	5.24401E-07	
		0.0	0.0	7.00000E-02	6.31000E-02	0.2092[illegible]2	4.43667E-02	3.71912E-05	
2	1	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801369	-3.68767E-02	2.90130E-03	8
		0.0	3.04000E-02	5.42000E-02	0.0	0.133044	2.17054E-02	8.37830E-06	
		-7.00000E-02	-6.31000E-02	-1.12600E-01	-1.25000E-01	-0.583187	-9.51270E-02	4.55695E-05	
	2	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801343	-3.68806E-02	2.90206E-03	9
		3.04000E-02	5.47000E-02	9.77000E-02	5.42000E-02	0.373527	6.08244E-02	6.59336E-05	
		-6.31000E-02	-4.36000E-02	-7.79000E-02	-1.12600E-01	-0.467254	-7.62668E-02	1.11503E-04	
	3	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801698	-3.68875E-02	2.90175E-03	10
		5.47000E-02	6.82000E-02	1.21900E-01	9.77000E-02	0.538296	8.79070E-02	1.37311E-04	
		-4.36000E-02	-1.56000E-02	-2.78000E-02	-7.79000E-02	-0.259843	-4.23210E-02	2.48814E-04	

SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

INPUT SURFACE ELEMENT DATA

N	M	X	X	X	X	NX	XCENT	AREA	L
		Y	Y	Y	Y	NY	YCENT	DELTA V	
		Z	Z	Z	Z	NZ	ZCENT	VOLUME	
2	4	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801967	-3.68740E-02	2.90608E-03	11
		6.82000E-02	6.82000E-02	1.21900E-01	1.21900E-01	0.597369	9.75658E-02	1.69374E-04	
		-1.56000E-02	1.56000E-02	2.78000E-02	-2.78000E-02	0.0	1.86265E-09	4.18188E-04	
	5	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801698	-3.68875E-02	2.90175E-03	12
		6.82000E-02	5.47000E-02	9.77000E-02	1.21900E-01	0.538296	8.79070E-02	1.37311E-04	
		1.56000E-02	4.36000E-02	7.79000E-02	2.78000E-02	0.259843	4.23210E-02	5.55499E-04	
	6	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801343	-3.68808E-02	2.90207E-03	13
		5.47000E-02	3.04000E-02	5.42000E-02	9.77000E-02	0.373527	6.08244E-02	6.59337E-05	
		4.36000E-02	6.31000E-02	1.12600E-01	7.79000E-02	0.467254	7.62669E-02	6.21432E-04	
	7	-1.50000E-02	-1.50000E-02	-5.50000E-02	-5.50000E-02	0.801369	-3.68767E-02	2.90130E-03	14
		3.04000E-02	0.0	0.0	5.42000E-02	0.133044	2.17054E-02	8.37830E-06	
		6.31000E-02	7.00000E-02	1.25000E-01	1.12600E-01	0.583187	9.51270E-02	6.29811E-04	
3	1	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.458440	-9.15071E-02	5.02903E-03	15
		0.0	5.42000E-02	7.03000E-02	0.0	0.197652	3.13005E-02	3.11126E-05	
		-1.25000E-01	-1.12600E-01	-1.46000E-01	-1.62000E-01	-0.866468	-1.37157E-01	6.60923E-04	
	2	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.458817	-9.15069E-02	5.03403E-03	16
		5.42000E-02	9.77000E-02	1.26700E-01	7.03000E-02	0.554128	8.77102E-02	2.44667E-04	
		-1.12600E-01	-7.79000E-02	-1.01000E-01	-1.46000E-01	-0.694571	-1.09983E-01	9.05590E-04	
	3	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.458068	-9.15034E-02	5.02955E-03	17
		9.77000E-02	1.21900E-01	1.57900E-01	1.26700E-01	0.800966	1.26746E-01	5.10595E-04	
		-7.79000E-02	-2.78000E-02	-3.60000E-02	-1.01000E-01	-0.385522	-6.10154E-02	1.41619E-03	
	4	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.457348	-9.14994E-02	5.02199E-03	18
		1.21900E-01	1.21900E-01	1.57900E-01	1.57900E-01	0.889288	1.40671E-01	6.28236E-04	
		-2.78000E-02	2.78000E-02	3.60000E-02	-3.60000E-02	0.0	4.65661E-09	2.04442E-03	
	5	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.458068	-9.15034E-02	5.02955E-03	19
		1.21900E-01	9.77000E-02	1.26700E-01	1.57900E-01	0.800966	1.26746E-01	5.10595E-04	
		2.78000E-02	7.79000E-02	1.01000E-01	3.60000E-02	0.385522	6.10154E-02	2.55502E-03	
	6	-5.50000E-02	-5.50000E-02	-1.25000E-01	-1.25000E-01	0.458817	-9.15069E-02	5.03403E-03	20
		9.77000E-02	5.42000E-02	7.03000E-02	1.26700E-01	0.554128	8.77102E-02	2.44667E-04	
		7.79000E-02	1.12600E-01	1.46000E-01	1.01000E-01	0.694571	1.09983E-01	2.79968E-03	

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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE    67                                                                                PAGE    6

SECTIONS A,C,G,K   **NOSE AND LEADING EDGES**

  INPUT SURFACE ELEMENT DATA

     N    M        X             X             X             X           NX         XCENT          AREA        L
                   Y             Y             Y             Y           NY         YCENT        DELTA V
                   Z             Z             Z             Z           NZ         ZCENT        VOLUME


     3    7  -5.50000E-02  -5.50000E-02  -1.25000E-01  -1.25000E-01  0.458440  -9.15071E-02   5.02903E-03   21
              5.42000E-02   0.0           0.0           7.03000E-02  0.197652   3.13005E-02   3.11126E-05
              1.12600E-01   1.25000E-01   1.62000E-01   1.46000E-01  0.866468   1.37157E-01   2.83080E-03

  SECTION = A    TOTAL AREA OF INPUT ELEMENTS =        0.063      TOTAL NUMBER OF ELEMENTS =   21
               TOTAL VOLUME OF INPUT ELEMENTS =        0.003

                 *********                   *********                   *********

     1    1  -1.25000E-01  -1.25000E-01  -1.00000E 00  -1.00000E 00  0.092457  -5.60039E-01   6.30997E-02   22
              0.0           7.10000E-02   2.64000E-01   1.95000E-01  0.221871   1.31955E-01   1.84737E-03
             -1.62000E-01  -1.45000E-01  -1.85000E-01  -2.00000E-01 -0.970683  -1.72890E-01   4.67816E-03

          2  -1.25000E-01  -1.25000E-01  -1.00000E 00  -1.00000E 00  0.170213  -5.66962E-01   6.32384E-02   23
              7.10000E-02   1.25000E-01   3.22000E-01   2.64000E-01  0.608806   1.96495E-01   7.56504E-03
             -1.45000E-01  -1.02000E-01  -1.40000E-01  -1.85000E-01 -0.774845  -1.43198E-01   1.22432E-02

          3  -1.25000E-01  -1.25000E-01  -1.00000E 00  -1.00000E 00  0.215659  -5.63850E-01   6.47200E-02   24
              1.25000E-01   1.57000E-01   3.55000E-01   3.22000E-01  0.872024   2.40055E-01   1.35481E-02
             -1.02000E-01  -3.80000E-02  -7.50000E-02  -1.40000E-01 -0.439392  -8.88072E-02   2.57913E-02

          4  -1.25000E-01  -1.25000E-01  -1.00000E 00  -1.00000E 00  0.223852  -5.66178E-01   3.53001E-02   25
              1.57000E-01   1.62000E-01   3.60000E-01   3.55000E-01  0.966712   2.59332E-01   8.84971E-03
             -3.80000E-02   0.0          -3.50000E-02  -7.50000E-02 -0.123938  -3.71515E-02   3.46410E-02

          5  -1.25000E-01  -1.25000E-01  -1.00000E 00  -1.00000E 00  0.208736  -6.03627E-01   4.77350E-02   26
              1.62000E-01   1.57000E-01   3.46000E-01   3.60000E-01  0.962344   2.65345E-01   1.21893E-02
              0.0           3.80000E-02   3.20000E-02  -3.50000E-02  0.174138   7.78269E-03   4.68303E-02

  SECTION = C    TOTAL AREA OF INPUT ELEMENTS =        0.337      TOTAL NUMBER OF ELEMENTS =   26
               TOTAL VOLUME OF INPUT ELEMENTS =        0.047

                 *********                   *********                   *********

     1    1  -1.00000E 00  -1.00000E 00  -1.60000E 01  -1.60000E 01  0.090336  -8.49998E 00   1.06352E 00   27
              1.95000E-01   2.64000E-01   2.98900E 00   2.92000E 00  0.211561   1.59200E 00   3.58199E-01
             -2.00000E-01  -1.85000E-01  -9.85000E-01  -1.00000E 00 -0.973181  -5.92499E-01   4.05029E-01

          2  -1.00000E 00  -1.00000E 00  -1.60000E 01  -1.60000E 01  0.151906  -8.43728E 00   1.08677E 00   28
              2.64000E-01   3.22000E-01   3.04400E 00   2.98900E 00  0.607292   1.64336E 00   1.08460E 00
             -1.85000E-01  -1.40000E-01  -9.42000E-01  -9.85000E-01 -0.779822  -5.59651E-01   1.48963E 00
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE    67                                                                                PAGE    7

SECTIONS A,C,G,K   **NOSE AND LEADING EDGES**

  INPUT SURFACE ELEMENT DATA

     N    M        X             X             X             X           NX         XCENT          AREA        L
                   Y             Y             Y             Y           NY         YCENT        DELTA V
                   Z             Z             Z             Z           NZ         ZCENT        VOLUME


     1    3  -1.00000E 00  -1.00000E 00  -1.60000E 01  -1.60000E 01  0.182960  -8.47678E 00   1.10197E 00   29
              3.22000E-01   3.55000E-01   3.07600E 00   3.04400E 00  0.877966   1.69504E 00   1.63993E 00
             -1.40000E-01  -7.50000E-02  -8.78000E-01  -9.42000E-01 -0.442382  -5.07507E-01   3.12956E 00

          4  -1.00000E 00  -1.00000E 00  -1.60000E 01  -1.60000E 01  0.183115  -8.46506E 00   6.06592E-01   30
              3.55000E-01   3.60000E-01   3.08000E 00   3.07600E 00  0.976773   1.71141E 00   1.01402E 00
             -7.50000E-02  -3.50000E-02  -8.39000E-01  -8.78000E-01 -0.111286  -4.54878E-01   4.14357E 00

          5  -1.00000E 00  -1.00000E 00  -1.60000E 01  -1.60000E 01  0.164777  -8.38004E 00   9.93178E-01   31
              3.60000E-01   3.46000E-01   3.06800E 00   3.08000E 00  0.966592   1.69174E 00   1.62407E 00
             -3.50000E-02   3.20000E-02  -7.78000E-01  -8.39000E-01  0.196339  -3.98546E-01   5.76764E 00

  SECTION = G    TOTAL AREA OF INPUT ELEMENTS =        5.189      TOTAL NUMBER OF ELEMENTS =   31
               TOTAL VOLUME OF INPUT ELEMENTS =        5.768

                 *********                   *********                   *********

     1    1  -1.60000E 01  -1.60000E 01  -3.00000E 01  -3.00000E 01  0.018419  -2.30160E 01   9.95565E-01   32
              2.92000E 00   2.98900E 00   4.21200E 00   4.14200E 00  0.210935   3.56715E 00   7.49098E-01
             -1.00000E 00  -9.85000E-01  -9.85000E-01  -1.00000E 00 -0.977327  -9.92500E-01   6.51674E 00

          2  -1.60000E 01  -1.60000E 01  -3.00000E 01  -3.00000E 01  0.053648  -2.29762E 01   9.68951E-01   33
              2.98900E 00   3.04400E 00   4.26600E 00   4.21200E 00  0.614052   3.62567E 00   2.15723E 00
             -9.85000E-01  -9.42000E-01  -9.43000E-01  -9.85000E-01 -0.787440  -9.63749E-01   8.67396E 00

          3  -1.60000E 01  -1.60000E 01  -3.00000E 01  -3.00000E 01  0.075445  -2.30146E 01   1.53161E 00   34
              3.04400E 00   3.09800E 00   4.32100E 00   4.26600E 00  0.863793   3.68352E 00   4.87327E 00
             -9.42000E-01  -8.48000E-01  -8.48000E-01  -9.43000E-01 -0.498167  -8.95250E-01   1.35472E 01

  SECTION = K    TOTAL AREA OF INPUT ELEMENTS =        8.685      TOTAL NUMBER OF ELEMENTS =   34
               TOTAL VOLUME OF INPUT ELEMENTS =       13.547

                 *********                   *********                   *********

     1    1  -1.00000E 00  -1.00000E 00  -1.00000E 00  -1.00000E 00  0.0       -1.00000E 00   0.0           35
              0.0           0.0           0.0           0.0          0.0        0.0           0.0
              0.0           0.0           0.0           0.0          0.0        0.0           1.35472E 01

  SECTION = K    TOTAL AREA OF INPUT ELEMENTS =        8.685      TOTAL NUMBER OF ELEMENTS =   35
               TOTAL VOLUME OF INPUT ELEMENTS =       13.547

                 *********                   *********                   *********
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 8

SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

ELEMENT DATA MACH= 19.084 ALT = 200000. S REF = 152.0 SPAN = 8.3 IMPACT = 1 IMPACI = 0
XCG = -18.6 YCG = 0.0 ZCG = 1.0 MAC = 30.0 ISHAD = 1 ISHADI = 0
ANGLE OF ATTACK = 12.00 YAW ANGLE = 0.0 K = 2.00000 ETAC = 1.0000 DELTA E = 0.0
IDERIV = 0 Q = 0.0 R = 0.0 P = 0.0

L	DEL CA CA	DEL CY CY	DEL CN CN	DEL CLL CLL	DEL CLM CLM	DEL CLN CLN	CP DELTA	AREA
1	0.27937E-04 0.27937E-04	0.0 0.0	0.59864E-05 0.59864E-05	0.0 0.0	0.27371E-05 0.27371E-05	0.0 0.0	0.19955E 01 0.87276E 02	0.10894E-02
2	0.27427E-04 0.55364E-04	0.0 0.0	0.47021E-05 0.10688E-04	0.0 0.0	0.19670E-05 0.47040E-05	0.0 0.0	0.19608E 01 0.81953E 02	0.10884E-02
3	0.26504E-04 0.81868E-04	0.0 0.0	0.25314E-05 0.13220E-04	0.0 0.0	0.66773E-06 0.53717E-05	0.0 0.0	0.19001E 01 0.77088E 02	0.10854E-02
4	0.25552E-04 0.10742E-03	0.0 0.0	-0.0 0.13220E-04	0.0 0.0	-0.85172E-06 0.45200E-05	0.0 0.0	0.18252E 01 0.72807E 02	0.10893E-02
5	0.24437E-04 0.13186E-03	0.0 0.0	-0.23340E-05 0.10886E-04	0.0 0.0	-0.22448E-05 0.22753E-05	0.0 0.0	0.17519E 01 0.69378E 02	0.10854E-02
6	0.23705E-04 0.15556E-03	0.0 0.0	-0.40640E-05 0.68219E-05	0.0 0.0	-0.32804E-05 -0.10052E-05	0.0 0.0	0.16947E 01 0.67003E 02	0.10884E-02
7	0.23281E-04 0.17884E-03	0.0 0.0	-0.49887E-05 0.18332E-05	0.0 0.0	-0.38329E-05 -0.48381E-05	0.0 0.0	0.16629E 01 0.65761E 02	0.10894E-02
8	0.50124E-04 0.22897E-03	0.0 0.0	0.36477E-04 0.38310E-04	0.0 0.0	0.20741E-04 0.15903E-04	0.0 0.0	0.16384E 01 0.64838E 02	0.29013E-02
9	0.47498E-04 0.27646E-03	0.0 0.0	0.27695E-04 0.66005E-04	0.0 0.0	0.15433E-04 0.31336E-04	0.0 0.0	0.15522E 01 0.61761E 02	0.29021E-02
10	0.43012E-04 0.31948E-03	0.0 0.0	0.13941E-04 0.79946E-04	0.0 0.0	0.71317E-05 0.38468E-04	0.0 0.0	0.14052E 01 0.56951E 02	0.29018E-02
11	0.37740E-04 0.35722E-03	0.0 0.0	-0.0 0.79946E-04	0.0 0.0	-0.12580E-05 0.37210E-04	0.0 0.0	0.12307E 01 0.51669E 02	0.29061E-02
12	0.32637E-04 0.38985E-03	0.0 0.0	-0.10578E-04 0.69368E-04	0.0 0.0	-0.75874E-05 0.29622E-04	0.0 0.0	0.10663E 01 0.46899E 02	0.29017E-02
13	0.28857E-04 0.41871E-03	0.0 0.0	-0.16826E-04 0.52541E-04	0.0 0.0	-0.11300E-04 0.18322E-04	0.0 0.0	0.94307E 00 0.43368E 02	0.29021E-02
14	0.26863E-04 0.44557E-03	0.0 0.0	-0.19549E-04 0.32992E-04	0.0 0.0	-0.12907E-04 0.54154E-05	0.0 0.0	0.87809E 00 0.41499E 02	0.29013E-02

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 9

SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

ELEMENT DATA MACH= 19.084 ALT = 200000. S REF = 152.0 SPAN = 8.3 IMPACT = 1 IMPACI = 0
XCG = -18.6 YCG = 0.0 ZCG = 1.0 MAC = 30.0 ISHAD = 1 ISHADI = 0
ANGLE OF ATTACK = 12.00 YAW ANGLE = 0.0 K = 2.00000 ETAC = 1.0000 DELTA E = 0.0
IDERIV = 0 Q = 0.0 R = 0.0 P = 0.0

L	DEL CA CA	DEL CY CY	DEL CN CN	DEL CLL CLL	DEL CLM CLM	DEL CLN CLN	CP DELTA	AREA
15	0.23971E-04 0.46954E-03	0.0 0.0	0.45306E-04 0.78299E-04	0.0 0.0	0.27043E-04 0.32459E-04	0.0 0.0	0.79020E 00 0.38945E 02	0.50290E-02
16	0.21388E-04 0.49093E-03	0.0 0.0	0.32378E-04 0.11068E-03	0.0 0.0	0.19184E-04 0.51643E-04	0.0 0.0	0.70[illegible]77E 00 0.36[illegible]84E 02	0.50340E-02
17	0.16916E-04 0.50785E-03	0.0 0.0	0.14237E-04 0.12491E-03	0.0 0.0	0.81851E-05 0.59828E-04	0.0 0.0	0.55802E 00 0.31885E 02	0.50295E-02
18	0.12096E-04 0.51994E-03	0.0 0.0	-0.0 0.12491E-03	0.0 0.0	-0.40320E-06 0.59425E-04	0.0 0.0	0.40025E 00 0.26574E 02	0.50220E-02
19	0.82062E-05 0.52815E-03	0.0 0.0	-0.69066E-05 0.11801E-03	0.0 0.0	-0.45179E-05 0.54907E-04	0.0 0.0	0.27071E 00 0.21586E 02	0.50295E-02
20	0.56313E-05 0.53378E-03	0.0 0.0	-0.85248E-05 0.10948E-03	0.0 0.0	-0.54264E-05 0.49480E-04	0.0 0.0	0.18530E 00 0.17721E 02	0.50340E-02
21	0.43665E-05 0.53815E-03	0.0 0.0	-0.82529E-05 0.10123E-03	0.0 0.0	-0.52172E-05 0.44263E-04	0.0 0.0	0.14394E 00 0.15562E 02	0.50290E-02
22	0.13113E-04 0.55126E-03	0.0 0.0	0.13767E-03 0.23890E-03	0.0 0.0	0.82272E-04 0.12654E-03	0.0 0.0	0.17082E 00 0.16993E 02	0.63100E-01
23	0.30399E-04 0.58166E-03	0.0 0.0	0.13838E-03 0.37728E-03	0.0 0.0	0.82023E-04 0.20856E-03	0.0 0.0	0.21463E 00 0.19123E 02	0.63238E-01
24	0.33566E-04 0.61522E-03	0.0 0.0	0.68389E-04 0.44567E-03	0.0 0.0	0.39898E-04 0.24846E-03	0.0 0.0	0.18277E 00 0.17596E 02	0.64720E-01
25	0.12454E-04 0.62768E-03	0.0 0.0	0.68955E-05 0.45256E-03	0.0 0.0	0.37145E-05 0.25217E-03	0.0 0.0	0.11978E 00 0.14166E 02	0.35300E-01
26	0.73979E-05 0.63508E-03	0.0 0.0	-0.61717E-05 0.44639E-03	0.0 0.0	-0.39470E-05 0.24822E-03	0.0 0.0	0.56427E-01 0.96698E 01	0.47735E-01
27	0.21365E-03 0.84873E-03	0.0 0.0	0.23017E-02 0.27480E-02	0.0 0.0	0.76355E-03 0.10118E-02	0.0 0.0	0.16901E 00 0.16900E 02	0.10635E 01
28	0.41944E-03 0.12682E-02	0.0 0.0	0.21532E-02 0.49013E-02	0.0 0.0	0.70761E-03 0.17194E-02	0.0 0.0	0.19309E 00 0.18103E 02	0.10868E 01

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 10

SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

ELEMENT DATA MACH= 19.084 ALT = 200000. S REF = 152.0 SPAN = 8.3 IMPACT = 1 IMPACI = 0
XCG = -18.6 YCG = 0.0 ZCG = 1.0 MAC = 30.0 ISHAD = 1 ISHADI = 0
ANGLE OF ATTACK = 12.00 YAW ANGLE = 0.0 K = 2.00000 ETAC = 1.0090 DELTA E = 0.0
IDERIV = 0 Q = 0.0 R = 0.0 P = 0.0

L	DEL CA CA	DEL CY CY	DEL CN CN	DEL CLL CLL	DEL CLM CLM	DEL CLN CLN	CP DELTA	AREA
29	0.38948E-03	0.0	0.94172E-03	0.0	0.29820E-03	0.0	0.14681E 00	0.11020E 01
	0.16576E-02	0.0	0.58430E-02	0.0	0.20176E-02	0.0	0.15720E 02	
30	0.11957E-03	0.0	0.72666E-04	0.0	0.18750E-04	0.0	0.81811E-01	0.60659E 00
	0.17772E-02	0.0	0.59156E-02	0.0	0.20363E-02	0.0	0.11669E 02	
31	0.62383E-04	0.0	-0.74332E-04	0.0	-0.28231E-04	0.0	0.28971E-01	0.99318E 00
	0.18396E-02	0.0	0.58413E-02	0.0	0.20081E-02	0.0	0.69126E 01	
32	0.23615E-04	0.0	0.12530E-02	0.0	-0.18601E-03	0.0	0.97871E-01	0.99556E 00
	0.18632E-02	0.0	0.70943E-02	0.0	0.18221E-02	0.0	0.12780E 02	
33	0.63938E-04	0.0	0.93847E-03	0.0	-0.14108E-03	0.0	0.93479E-01	0.96895E 00
	0.19271E-02	0.0	0.80328E-02	0.0	0.16810E-02	0.0	0.12486E 02	
34	0.95667E-04	0.0	0.63169E-03	0.0	-0.98999E-04	0.0	0.62921E-01	0.15316E 01
	0.20228E-02	0.0	0.86645E-02	0.0	0.15820E-02	0.0	0.10217E 02	
35	0.0	0.0	-0.0	0.0	0.0	0.0	0.0	0.0
	0.20228E-02	0.0	0.86645E-02	0.0	0.15820E-02	0.0	0.0	

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 11

SECTIONS A,C,G,K **NOSE AND LEADING EDGES**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA E
5.00	0.00173	0.00342	0.001^3	0.0	0.00355	2.00000	1	1.0000	0	0.0
0.0	1.97094	0.00078	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00215	0.00455	0.00158	0.0	0.00478	2.00000	1	1.0000	0	0.0
0.0	2.11920	0.00099	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00302	0.00655	0.00183	0.0	0.00698	2.00000	1	1.0000	0	0.0
0.0	2.17208	0.00133	0.0	0.0	0.0	1.00000	1	1.0000	0	
	-0.00082	-0.00059	0.00001							
12.00	0.00378	0.00805	0.00202	0.0	0.00866	2.00000	1	1.0000	0	0.0
0.0	2.13081	0.00158	0.0	0.0	0.0	1.00000	4	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00524	0.01052	0.00234	0.0	0.01151	2.00000	1	1.0000	0	0.0
0.0	2.00878	0.00198	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00524	0.01052	0.00234	0.0	0.01151	2.00000	1	1.0000	0	0.0
0.0	2.00878.	0.00198	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

SECTION = I TOTAL AREA OF INPUT ELEMENTS = 18.080 TOTAL NUMBER OF ELEMENTS = 10
TOTAL VOLUME OF INPUT ELEMENTS = 7.202

********* ********* *********

SECTION = E TOTAL AREA OF INPUT ELEMENTS = 18.282 TOTAL NUMBER OF ELEMENTS = 15
TOTAL VOLUME OF INPUT ELEMENTS = 7.215

********* ********* *********

SECTION = M TOTAL AREA OF INPUT ELEMENTS = 24.142 TOTAL NUMBER OF ELEMENTS = 25
TOTAL VOLUME OF INPUT ELEMENTS = 10.576

********* ********* *********

SECTION = Q TOTAL AREA OF INPUT ELEMENTS = 44.800 TOTAL NUMBER OF ELEMENTS = 30
TOTAL VOLUME OF INPUT ELEMENTS = 21.925

********* ********* *********

SECTION = Q TOTAL AREA OF INPUT ELEMENTS = 44.800 TOTAL NUMBER OF ELEMENTS = 31
TOTAL VOLUME OF INPUT ELEMENTS = 21.925

********* ********* *********

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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                   PAGE   12

SECTIONS  E,I,M,Q  **TOP**

  MACH=  19.084  VEL=  19999.9 FT/SEC  RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =   152.00  SPAN =    8.30  MAC  =   30.00
  X CG  =   -18.60  Y CG =    0.0   Z CG =    1.00

FORCE DATA                                                                  CONTROL DATA
  ALPHA     C D       C L       C A      C Y       C N        K              IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL     C LN      C F       Q/Q INF          ISHAD   ENPM   ISHADI
            CY B      CLN B     CLL B

   5.00   0.00086  -0.00473   0.00127   0.0     -0.00464   2.00000            5    1.0000    0       0.0
   0.0   -5.50396  -0.00164   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

   7.00   0.00046  -0.00225   0.00073   0.0     -0.00218   2.00000            5    1.0000    0       0.0
   0.0   -4.89660  -0.00102   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  10.00   0.00023   0.00013   0.00020   0.0      0.00017   2.00000            5    1.0000    0       0.0
   0.0    0.58803  -0.00040   0.0       0.0      0.0       1.00000            3    1.0000    0
         -0.00034  -0.00032  -0.00001

  12.80   0.00023   0.00103  -0.00001   0.0      0.00106   2.00000            5    1.0000    0       0.0
   0.0    4.52792  -0.00016   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  15.00   0.00028   0.00142  -0.00010   0.0      0.00145   2.00000            5    1.0000    0       0.0
   0.0    5.09666  -0.00006   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  15.00   0.00028   0.00142  -0.00010   0.0      0.00145   2.00000            5    1.0000    0      10.00
   0.0    5.09666  -0.00006   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

          THESE DATA HAVE BEEN SAVED FOR SUMMATION

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                   PAGE   13

INVISCID LEAD. EDGES AND TOP

  MACH=  19.084  VEL=  19999.9 FT/SEC  RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =   152.00  SPAN =    8.30  MAC  =   30.00
  X CG  =   -18.60  Y CG =    0.0   Z CG =    1.00

FORCE DATA                                                                  CONTROL DATA
  ALPHA     C D       C L       C A      C Y       C N        K              IMPACT  ETAC   IMPACI  DELTA E
  BETA      L/D       C M       C LL     C LN      C F       Q/Q INF          ISHAD   ENPM   ISHADI
            CY B      CLN B     CLL B

   5.00   0.00239  -0.00131   0.00270   0.0     -0.00108   2.00000            5    1.0000    0       0.0
   0.0   -0.50716  -0.00086   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

   7.00   0.00261   0.00231   0.00231   0.0      0.00261   2.00000            5    1.0000    0       0.0
   0.0    0.88409  -0.00003   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  10.00   0.00324   0.00669   0.00203   0.0      0.00715   2.00000            5    1.0000    0       0.0
   0.0    2.06064   0.00093   0.0       0.0      0.0       1.00000            3    1.0000    0
         -0.00116  -0.00091  -0.00000

  12.80   0.00401   0.00909   0.00202   0.0      0.00972   2.00000            5    1.0000    0       0.0
   0.0    2.26709   0.00142   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  15.00   0.00552   0.01194   0.00224   0.0      0.01296   2.00000            5    1.0000    0       0.0
   0.0    2.16515   0.00193   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

  15.00   0.00552   0.01194   0.00224   0.0      0.01296   2.00000            5    1.0000    0      10.00
   0.0    2.16515   0.00193   0.0       0.0      0.0       1.00000            3    1.0000    0
          0.0       0.0       0.0

          THESE DATA ARE THE SUMMATION OF   2 COMPONENTS PREVIOUSLY SAVED


SECTION = D   TOTAL AREA OF INPUT ELEMENTS =       0.128     TOTAL NUMBER OF ELEMENTS =    2
            TOTAL VOLUME OF INPUT ELEMENTS =       0.026

              *********                *********                *********

SECTION = H   TOTAL AREA OF INPUT ELEMENTS =      28.333     TOTAL NUMBER OF ELEMENTS =    8
            TOTAL VOLUME OF INPUT ELEMENTS =      41.545

              *********                *********                *********

SECTION = L   TOTAL AREA OF INPUT ELEMENTS =      39.060     TOTAL NUMBER OF ELEMENTS =   14
            TOTAL VOLUME OF INPUT ELEMENTS =      63.570

              *********                *********                *********

SECTION = P   TOTAL AREA OF INPUT ELEMENTS =      67.211     TOTAL NUMBER OF ELEMENTS =   15
            TOTAL VOLUME OF INPUT ELEMENTS =     115.432

              *********                *********                *********

SECTION = P   TOTAL AREA OF INPUT ELEMENTS =      67.211     TOTAL NUMBER OF ELEMENTS =   16
            TOTAL VOLUME OF INPUT ELEMENTS =     115.432

              *********                *********                *********
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                         PAGE   14

SECTIONS O,H,L,P  **WEDGE SIDES**

  MACH=  19.084  VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT =  200000.

  S REF =    152.00  SPAN =     8.30  MAC   =    30.00
  X CG  =    -18.60  Y CG =     0.0   Z CG  =     1.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N        K                   IMPACT  ETAC   IMPACI   DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF              ISHAD   ENPM   ISHADI
             CY B      CLN B     CLL B

   5.00   0.00100  -0.00329   0.00128   0.0      -0.00319   2.00000                5     1.0000   0       0.0
   0.0   -3.30118  -0.00105   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

   7.00   0.00069  -0.00227   0.00096   0.0      -0.00217   2.00000                5     1.0000   0       0.0
   0.0   -3.29181  -0.00082   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  10.00   0.00039  -0.00101   0.00056   0.0      -0.00093   2.00000                5     1.0000   0       0.0
   0.0   -2.56629  -0.00052   0.0       0.0       0.0       1.00000                3     1.0000   0
         -0.00168  -0.00137   0.00022

  12.80   0.00026  -0.00014   0.00029   0.0      -0.00008   2.00000                5     1.0000   0       0.0
   0.0   -0.52338  -0.00031   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  15.00   0.00023   0.00035   0.00013   0.0       0.00040   2.00000                5     1.0000   0       0.0
   0.0    1.53396  -0.00019   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  15.00   0.00023   0.00035   0.00013   0.0       0.00040   2.00000                5     1.0000   0      10.00
   0.0    1.53396  -0.00019   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

          THESE DATA HAVE BEEN SAVED FOR SUMMATION
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                         PAGE   15

INVISCID LEAD. EDGES, TOP, SIDES

  MACH=  19.084  VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT =  200000.

  S REF =    152.00  SPAN =     8.30  MAC   =    30.00
  X CG  =    -18.60  Y CG =     0.0   Z CG  =     1.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA     C D       C L       C A       C Y       C N        K                   IMPACT  ETAC   IMPACI   DELTA E
  BETA      L/D       C M       C LL      C LN      C F       Q/Q INF              ISHAD   ENPM   ISHADI
             CY B      CLN B     CLL B

   5.00   0.00359  -0.00461   0.00398   0.0      -0.00428   2.00000                5     1.0000   0       0.0
   0.0   -1.28336  -0.00192   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

   7.00   0.00330   0.00004   0.00327   0.0       0.00044   2.00000                5     1.0000   0       0.0
   0.0    0.01149  -0.00085   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  10.00   0.00364   0.00568   0.00260   0.0       0.00622   2.00000                5     1.0000   0       0.0
   0.0    1.55975   0.00041   0.0       0.0       0.0       1.00000                3     1.0000   0
         -0.00284  -0.00227   0.00022

  12.80   0.00427   0.00895   0.00230   0.0       0.00965   2.00000                5     1.0000   0       0.0
   0.0    2.09631   0.00111   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  15.00   0.00574   0.01229   0.00237   0.0       0.01336   2.00000                5     1.0000   0       0.0
   0.0    2.14018   0.00174   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

  15.00   0.00574   0.01229   0.00237   0.0       0.01336   2.00000                5     1.0000   0      10.00
   0.0    2.14018   0.00174   0.0       0.0       0.0       1.00000                3     1.0000   0
          0.0       0.0       0.0

          THESE DATA ARE THE SUMMATION OF   3 COMPONENTS PREVIOUSLY SAVED
```

SECTION = N   TOTAL AREA OF INPUT ELEMENTS =   17.721   TOTAL NUMBER OF ELEMENTS =   1
TOTAL VOLUME OF INPUT ELEMENTS =   66.364

*********   *********   *********

SECTION = N   TOTAL AREA OF INPUT ELEMENTS =   17.721   TOTAL NUMBER OF ELEMENTS =   2
TOTAL VOLUME OF INPUT ELEMENTS =   66.364

*********   *********   *********

SECTION N **AFT SIDE FIN**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	CONTROL DATA IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA E
5.00 0.0	0.00084 4.12326 0.0	0.00346 -0.00081 0.0	0.00053 0.0 0.0	0.0 0.0	0.00352 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
7.00 0.0	0.00124 3.57376 0.0	0.00445 -0.00105 0.0	0.00069 0.0 0.0	0.0 0.0	0.00457 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
10.00 0.0	0.00206 2.96587 -0.00204	0.00611 -0.00147 0.00175	0.00097 0.0 -0.00034	0.0 0.0	0.00637 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
12.80 0.0	0.00307 2.54744 0.0	0.00781 -0.00191 0.0	0.00126 0.0 0.0	0.0 0.0	0.00830 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00404 2.28537 0.0	0.00923 -0.00229 0.0	0.00151 0.0 0.0	0.0 0.0	0.00996 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00404 2.28537 0.0	0.00923 -0.00229 0.0	0.00151 0.0 0.0	0.0 0.0	0.00996 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	10.0

THESE DATA HAVE BEEN SAVED FOR SUMMATION

INVISCID L.E., TOP, SIDES, SIDE FIN

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	CONTROL DATA IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA E
5.00 0.0	0.00443 -0.25907 0.0	-0.00115 -0.00273 0.0	0.00451 0.0 0.0	0.0 0.0	-0.00076 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
7.00 0.0	0.00454 0.98775 0.0	0.00449 -0.00190 0.0	0.00396 0.0 0.0	0.0 0.0	0.00501 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
10.00 0.0	0.00570 2.06792 -0.00488	0.01178 -0.00106 -0.00053	0.00357 0.0 -0.00012	0.0 0.0	0.01259 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
12.80 0.0	0.00734 2.28490 0.0	0.01676 -0.00080 0.0	0.00356 0.0 0.0	0.0 0.0	0.01794 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00978 2.20014 0.0	0.02152 -0.00055 0.0	0.00388 0.0 0.0	0.0 0.0	0.02332 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00978 2.20014 0.0	0.02152 -0.00055 0.0	0.00388 0.0 0.0	0.0 0.0	0.02332 0.0	2.00000 1.00000	5 3	1.0000 1.0000	0 0	10.0

THESE DATA ARE THE SUMMATION OF 4 COMPONENTS PREVIOUSLY SAVED

SECTION = 0 TOTAL AREA OF INPUT ELEMENTS = 24.656 TOTAL NUMBER OF ELEMENTS = 1
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION = 0 TOTAL AREA OF INPUT ELEMENTS = 24.656 TOTAL NUMBER OF ELEMENTS = 2
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 18

SECTION 0 **AFT UPPER RAMP**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	K / Q/Q INF	IMPACT / ISHAD	ETAC / ENPM	IMPACI / ISHADI	DELTA E
5.00	0.00023	-0.00336	0.00052	0.0	-0.00333	2.00000	5	1.0000	0	0.0
0.0	-14.73427	0.00074	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00003	-0.00086	0.00013	0.0	-0.00085	2.00000	5	1.0000	0	0.0
0.0	-30.42249	0.00019	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00001	0.00053	-0.00008	0.0	0.00053	2.00000	5	1.0000	0	0.0
0.0	51.27208	-0.00012	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
12.80	0.00008	0.00112	-0.00017	0.0	0.00111	2.00000	5	1.0000	0	0.0
0.0	14.60343	-0.00025	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00013	0.00123	-0.00019	0.0	0.00123	2.00000	5	1.0000	0	0.0
0.0	9.33050	-0.00027	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00013	0.00123	-0.00019	0.0	0.00123	2.00000	5	1.0000	0	10.0
0.0	9.33050	-0.00027	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 19

INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	K / Q/Q INF	IMPACT / ISHAD	ETAC / ENPM	IMPACI / ISHADI	DELTA E
5.00	0.00466	-0.00451	0.00503	0.0	-0.00409	2.00000	5	1.0000	0	0.0
0.0	-0.96893	-0.00199	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00457	0.00362	0.00409	0.0	0.00415	2.00000	5	1.0000	0	0.0
0.0	0.79270	-0.00171	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00571	0.01231	0.00348	0.0	0.01312	2.00000	5	1.0000	0	0.0
0.0	2.15745	-0.00117	0.0	0.0	0.0	1.00000	3	1.0000	0	
	-0.00488	-0.00053	-0.00012							
12.80	0.00741	0.01788	0.00339	0.0	0.01905	2.00000	5	1.0000	0	0.0
0.0	2.41209	-0.00104	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00991	0.02275	0.00369	0.0	0.02454	2.00000	5	1.0000	0	0.0
0.0	2.29521	-0.00083	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00991	0.02275	0.00369	0.0	0.02454	2.00000	5	1.0000	0	10.0
0.0	2.29521	-0.00083	0.0	0.0	0.0	1.00000	3	1.0000	0	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF 5 COMPONENTS PREVIOUSLY SAVED

SECTION = R   TOTAL AREA OF INPUT ELEMENTS =   1.546   TOTAL NUMBER OF ELEMENTS =   3
TOTAL VOLUME OF INPUT ELEMENTS =   0.076

*********   *********   *********

SECTION = R   TOTAL AREA OF INPUT ELEMENTS =   1.546   TOTAL NUMBER OF ELEMENTS =   4
TOTAL VOLUME OF INPUT ELEMENTS =   0.076

*********   *********   *********

SECTION R   **VERTICAL FIN LEADING EDGE**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA   CONTROL DATA

ALPHA	C D	C L	C A	C Y	C N	K	IMPACT	ETAC	IMPACI	DELTA E
BETA	L/D	C M	C LL	C LN	C F	Q/Q INF	ISHAD	ENPM	ISHADI	
	CY B	CLN B	CLL B							
5.00	0.00053	-0.00125	0.00063	0.0	-0.00120	2.00000	1	1.0000	0	0.0
0.0	-2.37199	0.00041	0.0	0.0	0.0	0.31400	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00022	-0.00057	0.00028	0.0	-0.00053	2.00000	1	1.0000	0	0.0
0.0	-2.62428	0.00019	0.0	0.0	0.0	0.16700	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00003	-0.00009	0.00005	0.0	-0.00009	2.00000	1	1.0000	0	0.0
0.0	-3.10353	0.00003	0.0	0.0	0.0	0.03600	1	1.0000	0	
	-0.00000	0.00000	-0.00000							
12.00	0.00001	-0.00003-	0.00002	0.0	-0.00003	2.00000	1	1.0000	0	0.0
0.0	-3.51993	0.00001	0.0	0.0	0.0	0.01700	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00000	0.0	0.0	0.0	0.0	2.00000	1	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00000	0.0	0.0	0.0	0.0	2.00000	1	1.0000	0	10.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP, TAIL L.E.

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA   CONTROL DATA

ALPHA	C D	C L	C A	C Y	C N	K	IMPACT	ETAC	IMPACI	DELTA E
BETA	L/D	C M	C LL	C LN	C F	Q/Q INF	ISHAD	ENPM	ISHADI	
	CY B	CLN B	CLL B							
5.00	0.00518	-0.00576	0.00566	0.0	-0.00529	2.00000	1	1.0000	0	0.0
0.0	-1.11126	-0.00157	0.0	0.0	0.0	0.31400	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00478	0.00306	0.00438	0.0	0.00362	2.00000	1	1.0000	0	0.0
0.0	0.63893	-0.00152	0.0	0.0	0.0	0.16700	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00574	0.01222	0.00353	0.0	0.01303	2.00000	1	1.0000	0	0.0
0.0	2.13026	-0.00114	0.0	0.0	0.0	0.03600	1	1.0000	0	
	-0.00488	-0.00052	-0.00012							
12.00	0.00742	0.01784	0.00341	0.0	0.01902	2.00000	1	1.0000	0	0.0
0.0	2.40417	-0.00103	0.0	0.0	0.0	0.01700	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00991	0.02275	0.00369	0.0	0.02454	2.00000	1	1.0000	0	0.0
0.0	2.29498	-0.00083	0.0	0.0	0.0	0.0	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00991	0.02275	0.00369	0.0	0.02454	2.00000	1	1.0000	0	10.0
0.0	2.29498	-0.00083	0.0	0.0	0.0	0.0	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF   6 COMPONENTS PREVIOUSLY SAVED

SECTION = 5   TOTAL AREA OF INPUT ELEMENTS =   15.111   TOTAL NUMBER OF ELEMENTS =   1
TOTAL VOLUME OF INPUT ELEMENTS =   2.508

*********   *********   *********

SECTION = 5   TOTAL AREA OF INPUT ELEMENTS =   15.111   TOTAL NUMBER OF ELEMENTS =   2
TOTAL VOLUME OF INPUT ELEMENTS =   2.508

*********   *********   *********

SECTION 5 **VERTICAL TAIL SIDES**

MACH= 19.084   VEL= 19999.9 FT/SEC   RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00   SPAN = 8.30   MAC = 30.00
X CG = -18.60   Y CG = 0.0   Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	K / Q/Q INF	IMPACT / ISHAD	ETAC / ENPN	IMPACI / ISHADI	DELTA E
5.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.69000	3	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.31000	3	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.07500	3	1.0000	0	
	-0.00002	0.00003	-0.00001							
12.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.04100	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.01100	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00000	0.0	0.0	0.0	0.0	2.00000	3	1.0000	0	10.0
0.0	0.0	0.0	0.0	0.0	0.0	0.01100	3	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

INVISCID L.E., TOP, SIDES, SIDE FIN, UPPER RAMP, TAIL

MACH= 19.084   VEL= 19999.9 FT/SEC   RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00   SPAN = 8.30   MAC = 30.00
X CG = -18.60   Y CG = 0.0   Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	K / Q/Q INF	IMPACT / ISHAD	ETAC / ENPN	IMPACI / ISHADI	DELTA E
5.00	0.00518	-0.00576	0.00566	0.0	-0.00529	2.00000	3	1.0000	0	0.0
0.0	-1.11105	-0.00157	0.0	0.0	0.0	0.69000	3	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00479	0.00306	0.00438	0.0	0.00362	2.00000	3	1.0000	0	0.0
0.0	0.63880	-0.00152	0.0	0.0	0.0	0.31000	3	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00574	0.01222	0.00353	0.0	0.01303	2.00000	3	1.0000	0	0.0
0.0	2.12989	-0.00114	0.0	0.0	0.0	0.07500	3	1.0000	0	
	-0.00491	-0.00049	-0.00013							
12.00	0.00742	0.01784	0.00341	0.0	0.01902	2.00000	3	1.0000	0	0.0
0.0	2.40385	-0.00103	0.0	0.0	0.0	0.04100	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00992	0.02275	0.00369	0.0	0.02454	2.00000	3	1.0000	0	0.0
0.0	2.29474	-0.00083	0.0	0.0	0.0	0.01100	3	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00992	0.02275	0.00369	0.0	0.02454	2.00000	3	1.0000	0	10.0
0.0	2.29474	-0.00083	0.0	0.0	0.0	0.01100	3	1.0000	0	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF 7 COMPONENTS PREVIOUSLY SAVED

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SECTION = B   TOTAL AREA OF INPUT ELEMENTS =       0.085      TOTAL NUMBER OF ELEMENTS =     1
              TOTAL VOLUME OF INPUT ELEMENTS =     0.0

              *********                 *********                 *********

SECTION = F   TOTAL AREA OF INPUT ELEMENTS =      23.706      TOTAL NUMBER OF ELEMENTS =     2
              TOTAL VOLUME OF INPUT ELEMENTS =     0.0

              *********                 *********                 *********

SECTION = F   TOTAL AREA OF INPUT ELEMENTS =      23.706      TOTAL NUMBER OF ELEMENTS =     3
              TOTAL VOLUME OF INPUT ELEMENTS =     C.0

              *********                 *********                 *********
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                              PAGE   24

SECTIONS B,F **BOTTOM RAMP**

  MACH=  19.084  VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =   152.00  SPAN =    8.30  MAC   =   30.00
  X CG  =   -18.60  Y CG =    0.0   Z CG  =    1.00

FORCE DATA                                                                   CONTROL DATA
  ALPHA    C D       C L       C A       C Y       C N       K                 IMPACT  ETAC    IMPACI   DELTA E
  BETA     L/D       C M       C LL      C LN      C F       Q/Q INF           ISHAD   ENPM    ISHADI
           CY B      CLN B     CLL B

   5.00    0.00183   0.01296   0.00070   0.0       0.01307   2.00000             5     1.0000    0        0.0
   0.0     7.06961   0.00342   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

   7.00    0.00352   0.01985   0.00107   0.0       0.02013   2.00000             5     1.0000    0        0.0
   0.0     5.64188   0.00527   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  10.00    0.00757   0.03266   0.00178   0.0       0.03348   2.00000             5     1.0000    0        0.0
   0.0     4.31395   0.00876   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.00000  -0.00000

  12.00    0.01148   0.04271   0.00235   0.0       0.04416   2.00000             5     1.0000    0        0.0
   0.0     3.71881   0.01156   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  15.00    0.01947   0.05974   0.00334   0.0       0.06274   2.00000             5     1.0000    0        0.0
   0.0     3.06839   0.01642   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  15.00    0.01947   0.05974   0.00334   0.0       0.06274   2.00000             5     1.0000    0       10.0
   0.0     3.06839   0.01642   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

           THESE DATA HAVE BEEN SAVED FOR SUMMATION
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                              PAGE   25

INVISCID  ALL UPPER SURFACES, TAIL, RAMP.

  MACH=  19.084  VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =   152.00  SPAN =    8.30  MAC   =   30.00
  X CG  =   -18.60  Y CG =    0.0   Z CG  =    1.00

FORCE DATA                                                                   CONTROL DATA
  ALPHA    C D       C L       C A       C Y       C N       K                 IMPACT  ETAC    IMPACI   DELTA E
  BETA     L/D       C M       C LL      C LN      C F       Q/Q INF           ISHAD   ENPM    ISHADI
           CY B      CLN B     CLL B

   5.00    0.00702   0.00720   0.00636   0.0       0.00779   2.00000             5     1.0000    0        0.0
   0.0     1.02668   0.00185   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

   7.00    0.00830   0.02290   0.00545   0.0       0.02374   2.00000             5     1.0000    0        0.0
   0.0     2.75833   0.00374   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  10.00    0.01331   0.04488   0.00531   0.0       0.04651   2.00000             5     1.0000    0        0.0
   0.0     3.37221   0.00762   0.0       0.0       0.0       1.00000             3     1.0000    0
          -0.00491  -0.00049  -0.00013

  12.00    0.01891   0.06055   0.00576   0.0       0.06318   2.00000             5     1.0000    0        0.0
   0.0     3.20254   0.01053   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  15.00    0.02938   0.08249   0.00703   0.0       0.08729   2.00000             5     1.0000    0        0.0
   0.0     2.80733   0.01560   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

  15.00    0.02938   0.08249   0.00703   0.0       0.08729   2.00000             5     1.0000    0       10.0
   0.0     2.80733   0.01560   0.0       0.0       0.0       1.00000             3     1.0000    0
           0.0       0.0       0.0

           THESE DATA ARE THE SUMMATION OF    8 COMPONENTS PREVIOUSLY SAVED
```

```
SECTION =J1    TOTAL AREA OF INPUT ELEMENTS =        14.100       TOTAL NUMBER OF ELEMENTS =     2
               TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                      *********                    *********                    *********

SECTION =J1    TOTAL AREA OF INPUT ELEMENTS =        14.100       TOTAL NUMBER OF ELEMENTS =     3
               TOTAL VOLUME OF INPUT ELEMENTS =       0.0

                      *********                    *********                    *********


SHK-EXP. LOCAL CONDITIONS  LL=    1  N=    1  M=    1  P= 0.15323E 02  T= 0.30253E 04  MACH=  7.126  CP= 0.14147E 00
                          TURN ANGLE  =  15.0339    PI= 0.41338E 00 TI= 0.45699E 03 MACHI= 19.084
```

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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                    PAGE   26

SECTION J1 **AFT INBOARD FLAT**

ELEMENT DATA    MACH= 19.084  ALT = 200000.  S REF =    152.0  SPAN =    8.3  IMPACT =  9  IMPACI =  5
                XCG =  -18.6  YCG =    0.0    ZCG  =     1.0    MAC =   30.0   ISHAD =  7  ISHADI =  3
     ANGLE OF ATTACK = 12.00   YAW ANGLE =  0.0    K = 2.00000   ETAC =  1.0000   DELTA E =  0.0
     IDERIV =  0    Q = 0.0              R = 0.0             P = 0.0

  L       DEL CA          DEL CY          DEL CN          DEL CLL         DEL CLM         DEL CLN        CP              AREA
            CA              CY              CN              CLL             CLM             CLN          DELTA

  1   0.98657E-05    0.0             0.18614E-03    0.0             0.15786E-04    0.0             0.14147E 00    0.10014E 00
      0.98657E-05    0.0             0.18614E-03    0.0             0.15786E-04    0.0             0.15034E 02

SHK-EXP. LOCAL CONDITIONS  LL=    2  N=    2  M=    1  P= 0.87842E 01  T= 0.25806E 04  MACH=  7.771  CP= 0.79426E-01
                          TURN ANGLE  =  -3.0339    PI= 0.15323E 02 TI= 0.30253E 04 MACHI=  7.126

  2   0.0            0.0             0.14631E-01    0.0            -0.21459E-02    0.0             0.79426E-01    0.14000E 02
      0.98657E-05    0.0             0.14817E-01    0.0            -0.21301E-02    0.0             0.12000E 02

SHK-EXP. LOCAL CONDITIONS  LL=    3  N=    1  M=    1  P= 0.41341E 00  T= 0.45700E 03  MACH= 19.084  CP= 0.31047E-06
                          TURN ANGLE  =   0.0       PI= 0.41338E 00 TI= 0.45699E 03 MACHI= 19.084

  3   0.0            0.0            -0.0            0.0             0.0            0.0             0.31047E-06    0.0
      0.98657E-05    0.0             0.14817E-01    0.0            -0.21301E-02    0.0             0.0
```

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                    PAGE   27

SECTION J1 **AFT INBOARD FLAT**

  MACH=  19.084   VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =    152.00   SPAN =     8.30   MAC  =    30.00
  X CG  =    -18.60   Y CG =     0.0    Z CG =     1.00

FORCE DATA                                                                        CONTROL DATA
  ALPHA     C D        C L        C A        C Y        C N        K                IMPACT  ETAC    IMPACI   DELTA E
  BETA      L/D        C M        C LL       C LN       C F        Q/Q INF          ISHAD   ENPM    ISHADI
            CY B       CLN B      CLL B

   5.00   0.00024    0.00266    0.00000    0.0        0.00267    2.00000             9    1.0000     5       0.0
   0.0   11.28833   -0.00038    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0        0.0

   7.00   0.00062    0.00505    0.00000    0.0        0.00509    2.00000             9    1.0000     5       0.0
   0.0    8.08534   -0.00073    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0        0.0

  10.00   0.00179    0.01013    0.00001    0.0        0.01028    2.00000             9    1.0000     5       0.0
   0.0    5.64727   -0.00148    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0       -0.00000

  12.00   0.00309    0.01449    0.00001    0.0        0.01482    2.00000             9    1.0000     5       0.0
   0.0    4.68928   -0.00213    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0        0.0

  15.00   0.00602    0.02241    0.00001    0.0        0.02321    2.00000             9    1.0000     5       0.0
   0.0    3.72305   -0.00334    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0        0.0

  15.00   0.00602    0.02241    0.00001    0.0        0.02321    2.00000             9    1.0000     5      10.0
   0.0    3.72305   -0.00334    0.0        0.0        0.0        1.00000             7    1.0000     3
          0.0        0.0        0.0

        THESE DATA HAVE BEEN SAVED FOR SUMMATION
```

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 28

INVISCID ALL UPPER SURFACES, TAIL, RAMP, INBOARD FLAT

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA | CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA E
5.00	0.00725	0.00987	0.00636	0.0	0.01046	2.00000	9	1.0000	5	0.0
0.0	1.36054	0.00147	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
7.00	0.00893	0.02795	0.00545	0.0	0.02883	2.00000	9	1.0000	5	0.0
0.0	3.13096	0.00302	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
10.00	0.01510	0.05501	0.00532	0.0	0.05679	2.00000	9	1.0000	5	0.0
0.0	3.64232	0.00614	0.0	0.0	0.0	1.00000	7	1.0000	3	
	-0.00491	-0.00049	-0.00013							
12.00	0.02200	0.07504	0.00577	0.0	0.07800	2.00000	9	1.0000	5	0.0
0.0	3.41140	0.00840	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
15.00	0.03540	0.10490	0.00704	0.0	0.11049	2.00000	9	1.0000	5	0.0
0.0	2.96303	0.01225	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
15.00	0.03540	0.10490	0.00704	0.0	0.11049	2.00000	9	1.0000	5	10.0
0.0	2.96303	0.01225	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF 9 COMPONENTS PREVIOUSLY SAVED

SECTION =JO TOTAL AREA OF INPUT ELEMENTS = 35.694 TOTAL NUMBER OF ELEMENTS = 24
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION =EV TOTAL AREA OF INPUT ELEMENTS = 43.370 TOTAL NUMBER OF ELEMENTS = 39
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67 PAGE 29

SECTIONS JO,EV **OUTBOARD AFT FLAT AND ELEVON**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA | CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA E
5.00	0.00072	0.00815	0.00001	0.0	0.00818	2.00000	9	1.0000	5	0.0
0.0	11.34073	-0.00170	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
7.00	0.00191	0.01547	0.00001	0.0	0.01559	2.00000	9	1.0000	5	0.0
0.0	8.10728	-0.00324	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
10.00	0.00549	0.03107	0.00001	0.0	0.03155	2.00000	9	1.0000	5	0.0
0.0	5.65624	-0.00658	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.00000	-0.00000							
12.00	0.00947	0.04448	0.00002	0.0	0.04548	2.00000	9	1.0000	5	0.0
0.0	4.69502	-0.00949	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
15.00	0.01847	0.06883	0.00003	0.0	0.07127	2.00000	9	1.0000	5	0.0
0.0	3.72642	-0.01489	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							
15.00	0.02587	0.08256	0.00362	0.0	0.08644	2.00000	9	1.0000	5	10.00
0.0	3.19157	-0.02044	0.0	0.0	0.0	1.00000	7	1.0000	3	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

```
TOTAL INVISCID DATA

  MACH=  19.084   VEL=  19999.9 FT/SEC   RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =    152.00  SPAN =    8.30  MAC   =   30.00
  X CG  =    -18.60  Y CG =    0.0   Z CG  =    1.00

FORCE DATA                                                                          CONTROL DATA
  ALPHA    C D       C L       C A       C Y       C N       K                      IMPACT  ETAC    IMPACI  DELTA E
  BETA     L/D       C M       C LL      C LN      C F       Q/Q INF                ISHAD   ENPN    ISHADI
           CY B      CLN B     CLL B

   5.00   0.00797   0.01802   0.00637   0.0       0.01864   2.00000                  9     1.0000    5      0.0
   0.0    2.26044  -0.00023   0.0       0.0       0.0       1.00000                  7     1.0000    3
          0.0       0.0       0.0

   7.00   0.01084   0.04343   0.00546   0.0       0.04442   2.00000                  9     1.0000    5      0.0
   0.0    4.00752  -0.00022   0.0       0.0       0.0       1.00000                  7     1.0000    3
          0.0       0.0       0.0

  10.00   0.02059   0.08607   0.00533   0.0       0.08834   2.00000                  9     1.0000    5      0.0
   0.0    4.17945  -0.00043   0.0       0.0       0.0       1.00000                  7     1.0000    3
         -0.00491  -0.00049  -0.00013

  12.00   0.03147   0.11953   0.00579   0.0       0.12348   2.00000                  9     1.0000    5      0.0
   0.0    3.79782  -0.00109   0.0       0.0       0.0       1.00000                  7     1.0000    3
          0.0       0.0       0.0

  15.00   0.05388   0.17373   0.00707   0.0       0.18176   2.00000                  9     1.0000    5      0.0
   0.0    3.22476  -0.00263   0.0       0.0       0.0       1.00000                  7     1.0000    3
          0.0       0.0       0.0

  15.00   0.06127   0.18746   0.01066   0.0       0.19693   2.00000                  9     1.0000    5     10.00
   0.0    3.05951  -0.00818   0.0       0.0       0.0       1.00000                  7     1.0000    3
          0.0       0.0       0.0

          THESE DATA ARE THE SUMMATION OF  10 COMPONENTS PREVIOUSLY SAVED
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LAMINAR SKIN FRICTION  **BODY SURFACES**

  INPUT SURFACE ELEMENT DATA

     N    M       X              X              X              X            NX          XCENT         AREA        L
                  Y              Y              Y              Y            NY          YCENT        DELTA V
                  Z              Z              Z              Z            NZ          ZCENT        VOLUME

     1    1  -1.25000E-01  -1.60000E 01  -1.60000E 01  -1.25000E-01   0.052714  -1.07083E 01   2.34482E 01    1
              0.0           2.95000E 00   0.0           0.0           0.0        9.83333E-01   0.0
             -1.62000E-01  -1.00000E 00  -1.00000E 00  -1.62000E-01  -0.998610  -7.20666E-01   0.0

 SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =     23.448     TOTAL NUMBER OF ELEMENTS =    1
               TOTAL VOLUME OF INPUT ELEMENTS =    0.0

                  *********                  *********                  *********

     1    1  -1.60000E 01  -3.00000E 01  -3.00000E 01  -1.60000E 01   0.0       -2.30000E 01   1.40000E 01    2
              1.00000E 00   1.00000E 00   0.0           0.0           0.0        5.00000E-01   0.0
             -1.00000E 00  -1.00000E 00  -1.00000E 00  -1.00000E 00  -1.000000  -1.00000E 00   0.0

 SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =     37.448     TOTAL NUMBER OF ELEMENTS =    2
               TOTAL VOLUME OF INPUT ELEMENTS =    0.0

                  *********                  *********                  *********

     1    1  -1.60000E 01  -3.25000E 01  -3.25000E 01  -1.60000E 01   0.0       -2.48762E 01   4.16625E 01    3
              2.95000E 00   4.10000E 00   1.00000E 00   1.00000E 00   0.0        2.28432E 00   0.0
             -1.00000E 00  -1.00000E 00  -1.00000E 00  -1.00000E 00  -1.000000  -1.00000E 00   0.0

 SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =     79.111     TOTAL NUMBER OF ELEMENTS =    3
               TOTAL VOLUME OF INPUT ELEMENTS =    0.0

                  *********                  *********                  *********

     1    1  -1.60000E 01  -3.00000E 01  -3.00000E 01  -1.60000E 01   0.075501  -2.53333E 01   1.77211E 01    4
              3.09800E 00   5.58000E 00   4.32100E 00   3.09800E 00   0.864278   4.33299E 00   6.63640E 01
             -8.48000E-01   1.34000E 00  -8.48000E-01  -8.48000E-01  -0.497316  -1.18667E-01   6.63640E 01

 SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =     96.832     TOTAL NUMBER OF ELEMENTS =    4
               TOTAL VOLUME OF INPUT ELEMENTS =   66.364

                  *********                  *********                  *********

     1    1  -1.25000E-01  -1.60000E 01  -1.60000E 01  -1.25000E-01   0.174633  -1.04365E 01   1.63537E 01    5
              0.0           0.0           1.60000E 00   1.00000E-01   0.537297   5.37119E-01   4.71956E 00
              1.62000E-01   3.55000E 00   2.48000E 00   1.25000E-01   0.825116   2.00868E 00   7.10836E 01

 SECTION =SF   TOTAL AREA OF INPUT ELEMENTS =    113.186     TOTAL NUMBER OF ELEMENTS =    5
               TOTAL VOLUME OF INPUT ELEMENTS =   71.084

                  *********                  *********                  *********
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE    67                                                                                    PAGE   32

LAMINAR SKIN FRICTION   **BODY SURFACES**

  INPUT SURFACE ELEMENT DATA

      N    M        X              X              X              X             NX          XCENT          AREA        L
                    Y              Y              Y              Y             NY          YCENT        DELTA V
                    Z              Z              Z              Z             NZ          ZCENT        VOLUME

      1    1  -1.60000E 01  -3.00000E 01  -3.00000E 01  -1.60000E 01  0.015497  -2.29019E 01   2.58633E 01      6
               0.0           0.0           1.48000E 00   1.60000E 00  0.552133   7.70422E-01   1.10016E 01
               3.55000E 00   3.80000E 00   2.83000E 00   2.48000E 00  0.833612   3.16289E 00   8.20852E 01

 SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =      139.049      TOTAL NUMBER OF ELEMENTS =    6
               TOTAL VOLUME OF INPUT ELEMENTS =      82.085

                  *********                 *********                 *********

      1    1  -1.25000E-01  -1.60000E 01  -1.60000E 01  -1.25000E-01  0.144915  -1.05622E 01   3.01095E 01      7
               1.00000E-01   1.60000E 00   3.09800E 00   1.57000E-01  0.900531   1.58837E 00   4.30678E 01
               1.26000E-01   2.48000E 00  -8.48000E-01   3.90000E-02  0.409932   5.64614E-01   1.25153E 02

 SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =      169.158      TOTAL NUMBER OF ELEMENTS =    7
               TOTAL VOLUME OF INPUT ELEMENTS =     125.153

                  *********                 *********                 *********

      1    1  -1.60000E 01  -3.00000E 01  -3.00000E 01  -1.60000E 01 -0.000075  -2.20974E 01   3.68409E 01      8
               1.60000E 00   1.48000E 00   2.10000E 00   3.09800E 00  0.915450   2.10554E 00   7.10113E 01
               2.48000E 00   2.83000E 00   1.34000E 00  -8.48000E-01  0.402433   1.36868E 00   1.96164E 02

 SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =      205.999      TOTAL NUMBER OF ELEMENTS =    8
               TOTAL VOLUME OF INPUT ELEMENTS =     196.164

                  *********                 *********                 *********

      1    1  -1.60000E 01   3.00000E 01  -3.00000E 01  -1.60000E 01  0.154411  -2.53333E 01   2.46557E 01      9
               3.09800E 00   2.10000E 00   5.58000E 00   3.09800E 00  0.0         3.59266E 00   0.0
              -8.48000E-01   1.34000E 00   1.34000E 00  -8.48000E-01  0.988007   6.10666E-01   1.96164E 02

 SECTION =SF    TOTAL AREA OF INPUT ELEMENTS =      230.655      TOTAL NUMBER OF ELEMENTS =    9
               TOTAL VOLUME OF INPUT ELEMENTS =     196.164

                  *********                 *********                 *********
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE    67                                                                                    PAGE   33

LAMINAR SKIN FRICTION   **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =    5.00       MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =     152.0

  NN= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1652.0R    CF1 = 0.205453E-02   CF1(RE1) = 1.451551     ROMURA =  4.94447   H*/H1 =  14.5191   HAW/H1 =  62.6363
  KT= 0    TWEQ = 1745.5R    CF1 = 0.305547E-02   CF1(RE1) = 0.042143     ROMURA =  0.21767   H*/H1 =  14.5191   HAW/H1 =  66.1609

 SKIN FRICTION DATA
          SURF NO.    TYPE     METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)  RE LOC     CHI BAR  V BAR
  LAM        CF        CA        CN      SUM CA    SUM CN      TW        TW/T       TW/TR   RE*/FT       CD     CF/CFO
  TURB       CF        CA        CN      SUM CA    SUM CN      TW        TW/T       TW/TR   RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF    TEMP-R   RHO*10**4 VIS*10**7    RE/FT  C STAR       C      V STAR

              1         1         2          24.     16.0        0.0      0.0         8.02  1.091E 06    8.074  0.0222
  LAM      0.00666   0.0       0.0        0.0       0.0       1652.0     3.6150     0.0577 3.994E 03  0.0       1.2150
  TURB     0.00418   0.0       0.0        0.0       0.0       1745.5     3.8195     0.0577 9.820E 04  0.0       1.0000
  STREAM 19.08449   19999.9   1047.97     0.4134    456.99 0.0052696  3.382647 3.116E 04 3.655E-01 6.735E-01 0.0163
  LOCAL  11.63035   19774.2   1700.22     4.8055   1202.94 0.0232724  6.757499 6.810E 04
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE    67                                                                                    PAGE   34

LAMINAR SKIN FRICTION   **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =    7.00       MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =     152.0

  NN= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1733.4R    CF1 = 0.247684E-02   CF1(RE1) = 1.749914     ROMURA =  7.32314   H*/H1 =  14.8666   HAW/H1 =  62.7766
  KT= 0    TWEQ = 1880.6R    CF1 = 0.410883E-02   CF1(RE1) = 0.056672     ROMURA =  0.27624   H*/H1 =  14.8666   HAW/H1 =  66.2571

 SKIN FRICTION DATA
          SURF NO.    TYPE     METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)  RE LOC     CHI BAR  V BAR
  LAM        CF        CA        CN      SUM CA    SUM CN      TW        TW/T       TW/TR   RE*/FT       CD     CF/CFO
  TURB       CF        CA        CN      SUM CA    SUM CN      TW        TW/T       TW/TR   RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF    TEMP-R   RHO*10**4 VIS*10**7    RE/FT  C STAR       C      V STAR

              1         1         2          24.     16.0        0.0      0.0        10.02  1.009E 06    7.998  0.0220
  LAM      0.00766   0.0       0.0        0.0       0.0       1733.4     3.7930     0.0604 5.713E 03  0.0       1.1593
  TURB     0.00558   0.0       0.0        0.0       0.0       1880.6     4.1152     0.0621 1.255E 05  0.0       1.0000
  STREAM 19.08449   19999.9   1047.97     0.4134    456.99 0.0052696  3.382647 3.116E 04 3.615E-01 6.609E-01 0.0162
  LOCAL   9.98846   19650.0   1967.27     7.1846   1610.49 0.0259888  8.109678 6.297E 04
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
 CASE    67                                                                                  PAGE   35

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =  10.00        MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =      152.0

  NW= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1836.0R   CFI = 0.307850E-02    CFI(REI) = 2.174997    ROMURA = 11.73826    H*/HI =  15.4580   HAW/HI =  63.0495
  KT= 0    TWEQ = 2050.0R   CFI = 0.574693E-02    CFI(REI) = 0.079265    ROMURA =  0.37914    H*/HI =  15.4580   HAW/HI =  66.4414

 SKIN FRICTION DATA
          SURF NO.    TYPE      METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)   RE LOC     CHI BAR  V BAR
  LAM        CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
  TURB       CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF     TEMP-R   RHO*10**4 VIS*10**7   RE/FT    C STAR       C      V STAR

             1          1          2          24.      16.0        0.0       0.0       13.02  8.639E 05    7.907  0.0217
  LAM     0.00910   0.0       0.0       0.0       0.0         1836.0    4.0175    0.0637 8.617E 03  0.0     1.1080
  TURB    0.00773   0.0       0.0       0.0       0.0         2050.0    4.4857    0.0675 1.696E 05  0.0     1.0000
  STREAM 19.08449   19999.9   1047.97   0.4134    456.99 0.0052696  3.382647 3.116E 04 3.549E-01 6.459E-01 0.0161
  LOCAL   8.09706   19409.8   2397.14   11.6874   2391.22 0.0284735 10.249096 5.392E 04

HYPERSON.C ARBITRARY-BODY PROGRAM, MARK III MOD 0
 CASE    67                                                                                  PAGE   36

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =  10.00        MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =      152.0

  NW= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1836.0R   CFI = 0.307850E-02    CFI(REI) = 2.174997    ROMURA = 11.73826    H*/HI =  15.4580   HAW/HI =  63.0495
  KT= 0    TWEQ = 2050.0R   CFI = 0.574693E-02    CFI(REI) = 0.079265    ROMURA =  0.37914    H*/HI =  15.4580   HAW/HI =  66.4414

 SKIN FRICTION DATA
          SURF NO.    TYPE      METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)   RE LOC     CHI BAR  V BAR
  LAM        CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
  TURB       CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF     TEMP-R   RHO*10**4 VIS*10**7   RE/FT    C STAR       C      V STAR

             1          1          2          24.      16.0        0.0       0.0       13.02  8.639E 05    7.907  0.0217
  LAM     0.00910   0.0       0.0       0.0       0.0         1836.0    4.0175    0.0637 8.617E 03  0.0     1.1080
  TURB    0.00773   0.0       0.0       0.0       0.0         2050.0    4.4857    0.0675 1.696E 05  0.0     1.0000
  STREAM 19.08449   19999.9   1047.97   0.4134    456.99 0.0052696  3.382647 3.116E 04 3.549E-01 6.459E-01 0.0161
  LOCAL   8.09706   19409.8   2397.14   11.6874   2391.22 0.0284735 10.249096 5.392E 04

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
 CASE    67                                                                                  PAGE   37

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =  10.00        MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =      152.0

  NW= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1836.0R   CFI = 0.307889E-02    CFI(REI) = 2.175272    ROMURA = 11.74156    H*/HI =  15.4584   HAW/HI =  63.0497
  KT= 0    TWEQ = 2050.1R   CFI = 0.574804E-02    CFI(REI) = 0.079281    ROMURA =  0.37921    H*/HI =  15.4584   HAW/HI =  66.4416

 SKIN FRICTION DATA
          SURF NO.    TYPE      METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)   RE LOC     CHI BAR  V BAR
  LAM        CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
  TURB       CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF     TEMP-R   RHO*10**4 VIS*10**7   RE/FT    C STAR       C      V STAR

             1          1          2          24.      16.0        0.0       0.0       13.02  8.638E 05    7.907  0.0217
  LAM     0.00910   0.0       0.0       0.0       0.0         1836.0    4.0176    0.0637 8.619E 03  0.0     1.1079
  TURB    0.00773   0.0       0.0       0.0       0.0         2050.1    4.4860    0.0675 1.696E 05  0.0     1.0000
  STREAM 19.08449   19999.9   1047.97   0.4134    456.99 0.0052696  3.382647 3.116E 04 3.549E-01 6.459E-01 0.0161
  LOCAL   8.09598   19409.6   2397.44   11.6908   2391.87 0.0284748 10.250560 5.392E 04

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
 CASE    67                                                                                  PAGE   38

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
          ALPHA =  12.00        MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
          RE/FT = 3.116E 04     S REF    =      152.0

  NW= 3    REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1    TWEQ = 1894.5R   CFI = 0.345108E-02    CFI(REI) = 2.438226    ROMURA = 15.20741    H*/HI =  15.9010   HAW/HI =  63.2625
  KT= 0    TWEQ = 2144.5R   CFI = 0.682725E-02    CFI(REI) = 0.094166    ROMURA =  0.45539    H*/HI =  15.9010   HAW/HI =  66.5901

 SKIN FRICTION DATA
          SURF NO.    TYPE      METHOD     S WET    LENGTH    ALPHA O    WEDGE     ANGLE(2)   RE LOC     CHI BAR  V BAR
  LAM        CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
  TURB       CF        CA         CN      SUM CA    SUM CN      TW        TW/T      TW/TR     RE*/FT       CD     CF/CFO
            MACH        V      V SOUND    P-PSF     TEMP-R   RHO*10**4 VIS*10**7   RE/FT    C STAR       C      V STAR

             1          1          2          24.      16.0        0.0       0.0       15.02  7.757E 05    7.857  0.0216
  LAM     0.00999   0.0       0.0       0.0       0.0         1894.5    4.1457    0.0655 1.066E 04  0.0     1.0861
  TURB    0.00914   0.0       0.0       0.0       0.0         2144.5    4.6927    0.0705 2.005E 05  0.0     1.0000
  STREAM 19.08449   19999.9   1047.97   0.4134    456.99 0.0052696  3.382647 3.116E 04 3.502E-01 6.377E-01 0.0160
  LOCAL   7.13088   19213.8   2694.45   15.2996   3021.16 0.0295018 11.707461 4.842E 04

ELEMENT DATA    MACH= 19.084   ALT  = 200000.   S REF  =    152.0  SPAN =     8.3   IMPACT =  1   IMPACI =  0
                XCG =   -18.6  YCG  =     0.0   ZCG    =      1.0  MAC  =    30.0   ISHAD  =  1   ISHADI =  0
      ANGLE OF ATTACK = 12.00     YAW ANGLE =  0.0     K = 2.00000    FTAC =  1.0000   DELTA E =  0.0
      IDERIV =  0    Q = 0.0              R = 0.0              P = 0.0

  L        DEL CA          DEL CY          DEL CN          DEL CLL         DEL CLM         DEL CLN         CP              AREA
             CA              CY              CN              CLL             CLM             CLN          DELTA

  1    0.31133E-02     0.0             -0.16434E-03    0.0             -0.22180E-03    0.0             0.0             0.23706E 02
       0.31133E-02     0.0             -0.16434E-03    0.0             -0.22180E-03    0.0             0.15022E 02
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                PAGE   39

LAMINAR SKIN FRICTION  **BODY SURFACES***

ELEMENT DATA   MACH= 19.084  ALT = 200000.  S REF =   152.0  SPAN =    8.3  IMPACT =  1  IMPACI =  0
               XCG =  -18.6  YCG =     0.0   ZCG  =     1.0   MAC =   30.0  ISHAD =  1  ISHADI =  0
     ANGLE OF ATTACK = 12.00   YAW ANGLE =  0.0    K = 2.00000   ETAC =  1.0000   DELTA E =  0.0
     IDERIV =  0   Q = 0.0             R = 0.0           P = 0.0

  L      DEL CA        DEL CY          DEL CN         DEL CLL         DEL CLM         DEL CLN       CP                AREA
           CA            CY              CN             CLL             CLM             CLN         DELTA

  2    0.49419E-03   0.0             0.0              0.0          -0.32946E-04      0.0           0.0             0.14100E 02
       0.36075E-02   0.0            -0.16434E-03      0.0          -0.25474E-03      0.0           0.12000E 02

  3    0.21255E-02   0.0             0.0              0.0          -0.14170E-03      0.0           0.0             0.43370E 02
       0.57330E-02   0.0            -0.16434E-03      0.0          -0.39644E-03      0.0           0.12000E 02

  4    0.13891E-02   0.0             0.17244E-03      0.0          -0.90501E-04      0.0           0.0             0.17721E 02
       0.71221E-02   0.0             0.80945E-05      0.0          -0.48694E-03      0.0           0.10210E 02

  5    0.57279E-03   0.0             0.12138E-03      0.0           0.52288E-04      0.0           0.0             0.18282E 02
       0.76949E-02   0.0             0.12947E-03      0.0          -0.43466E-03      0.0          -0.42114E-01

  6    0.89311E-04   0.0             0.69281E-05      0.0           0.54455E-05      0.0           0.0             0.26519E 02
       0.77842E-02   0.0             0.13640E-03      0.0          -0.42921E-03      0.0          -0.91001E 01

  7    0.10916E-02   0.0             0.26006E-03      0.0           0.53835E-04      0.0           0.0             0.28333E 02
       0.88758E-02   0.0             0.39646E-03      0.0          -0.37537E-03      0.0           0.32400E 01

  8    0.17987E-03   0.0             0.32036E-04      0.0          -0.15242E-05      0.0           0.0             0.38878E 02
       0.90557E-02   0.0             0.42850E-03      0.0          -0.37690E-03      0.0          -0.48038E 01

  9    0.68311E-03   0.0             0.10676E-03      0.0          -0.32827E-04      0.0           0.0             0.24656E 02
       0.97388E-02   0.0             0.53526E-03      0.0          -0.40973E-03      0.0          -0.31174E 01
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                PAGE   40

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
         ALPHA =  15.00      MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
         RE/FT = 3.116E 04   S REF    =     152.0

  NW= 3   REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1   TWEQ = 1970.7R   CFI = 0.395548E-02   CFI(REI) = 2.794593    ROMURA = 21.09767   H*/HI =  16.6359   HAW/HI =  63.6403
  KT= 0   TWEQ = 2265.5R   CFI = 0.835729E-02   CFI(REI) = 0.115269    ROMURA =  0.57732   H*/HI =  16.6359   HAW/HI =  66.8492

 SKIN FRICTION DATA
         SURF NO.   TYPE    METHOD    S WET   LENGTH   ALPHA C   WEDGE     ANGLE(2)  RE LOC      CHI BAR  V BAR
  LAM       CF       CA       CN      SUM CA  SUM CN     TW       TW/T      TW/TR    RE*/FT        CD    CF/CFO
  TURB      CF       CA       CN      SUM CA  SUM CN     TW       TW/T      TW/TR    RE*/FT        CD    CF/CFO
           MACH      V      V SOUND   P-PSF   TEMP-R  RHO*10**4 VIS*10**7   RE/FT    L STAR        C     V STAR

            1         1        2        24.     16.0       0.0      0.0      18.02  6.638E 05    7.794  0.0214
  LAM    0.01122  0.0       0.0      0.0      0.0       1970.7    4.3124   0.0678 1.371E 04  0.0      1.0639
  TURB   0.01112  0.0       0.0      0.0      0.0       2265.5    4.9575   0.0742 2.477E 05  0.0      1.0000
  STREAM 19.08449  19999.9  1047.97   0.4134   456.99 0.0052696  3.382647 3.116E 04 3.428E-01 6.276E-01 0.0158
  LOCAL   5.99746  18867.6  3145.94  21.5763  4118.44 0.0305201 13.897570 4.143E 04
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HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                PAGE   41

LAMINAR SKIN FRICTION  **BODY SURFACES***

 FREE STREAM CONDITIONS
         ALPHA =  15.00      MACH     = 19.08   VELOCITY =  19999.9   ALTITUDE = 200000.0
         RE/FT = 3.116E 04   S REF    =     152.0

  NW= 3   REAL  GAS, REF. H/S-C  SOLUTION.
  KT= 1   TWEQ = 1970.7R   CFI = 0.395548E-02   CFI(REI) = 2.794593    ROMURA = 21.09767   H*/HI =  16.6359   HAW/HI =  63.6403
  KT= 0   TWEQ = 2265.5R   CFI = 0.835729E-02   CFI(REI) = 0.115269    ROMURA =  0.57732   H*/HI =  16.6359   HAW/HI =  66.8492

 SKIN FRICTION DATA
         SURF NO.   TYPE    METHOD    S WET   LENGTH   ALPHA C   WEDGE     ANGLE(2)  RE LOC      CHI BAR  V BAR
  LAM       CF       CA       CN      SUM CA  SUM CN     TW       TW/T      TW/TR    RE*/FT        CD    CF/CFO
  TURB      CF       CA       CN      SUM CA  SUM CN     TW       TW/T      TW/TR    RE*/FT        CD    CF/CFO
           MACH      V      V SOUND   P-PSF   TEMP-R  RHO*10**4 VIS*10**7   RE/FT    L STAR        C     V STAR

            1         1        2        24.     16.0       0.0      0.0      18.02  6.638E 05    7.794  0.0214
  LAM    0.01122  0.0       0.0      0.0      0.0       1970.7    4.3124   0.0678 1.371E 04  0.0      1.0639
  TURB   0.01112  0.0       0.0      0.0      0.0       2265.5    4.9575   0.0742 2.477E 05  0.0      1.0000
  STREAM 19.08449  19999.9  1047.97   0.4134   456.99 0.0052696  3.382647 3.116E 04 3.428E-01 6.276E-01 0.0158
  LOCAL   5.99746  18867.6  3145.94  21.5763  4118.44 0.0305201 13.897570 4.143E 04
```

LAMINAR SKIN FRICTION **BODY SURFACES***

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA	C D	C L	C A	C Y	C N	K	IMPACT	ETAC	IMPACI	DELTA E
BETA	L/D	C M	C LL	C LN	C F	Q/Q INF	ISHAD	ENPM	ISHADI	
	CY B	CLN B	CLL B							
5.00	0.00843	-0.00025	0.00842	0.0	0.00049	2.00000	1	1.0000	0	0.0
0.0	-0.02971	-0.00022	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00869	-0.00058	0.00869	0.0	0.00048	2.00000	1	1.0000	0	0.0
0.0	-0.06707	-0.00027	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00925	-0.00112	0.00931	0.0	0.00051	2.00000	1	1.0000	0	0.0
0.0	-0.12091	-0.00036	0.0	0.0	0.0	1.00000	1	1.0000	0	
	-0.00011	0.00006	0.00001							
12.00	0.00964	-0.00150	0.00974	0.0	0.00054	2.00000	1	1.0000	0	0.0
0.0	-0.15578	-0.00041	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.01007	-0.00211	0.01028	0.0	0.00057	2.00000	1	1.0000	0	0.0
0.0	-0.20973	-0.00049	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.01006	-0.00211	0.01026	0.0	0.00057	2.00000	1	1.0000	0	10.00
0.0	-0.20964	-0.00049	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

INVISCID PLUS BODY SURFACES SKIN FRICTION

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA	C D	C L	C A	C Y	C N	K	IMPACT	ETAC	IMPACI	DELTA E
BETA	L/D	C M	C LL	C LN	C F	Q/Q INF	ISHAD	ENPM	ISHADI	
	CY B	CLN B	CLL B							
5.00	0.01640	0.01777	0.01479	0.0	0.01913	2.00000	1	1.0000	0	0.0
0.0	1.08335	-0.00044	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.01952	0.04284	0.01416	0.0	0.04490	2.00000	1	1.0000	0	0.0
0.0	2.19443	-0.00050	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.02985	0.08495	0.01464	0.0	0.08885	2.00000	1	1.0000	0	0.0
0.0	2.84623	-0.00080	0.0	0.0	0.0	1.00000	1	1.0000	0	
	-0.00501	-0.00244	-0.00012							
12.00	0.04111	0.11803	0.01553	0.0	0.12401	2.00000	1	1.0000	0	0.0
0.0	2.87100	-0.00150	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.06395	0.17162	0.01735	0.0	0.18232	2.00000	1	1.0000	0	0.0
0.0	2.68376	-0.00312	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.07133	0.18535	0.02092	0.0	0.19750	2.00000	1	1.0000	0	10.00
0.0	2.59856	-0.00867	0.0	0.0	0.0	1.00000	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF 11 COMPONENTS PREVIOUSLY SAVED

SECTION = TOTAL AREA OF INPUT ELEMENTS = 15.111 TOTAL NUMBER OF ELEMENTS = 1
TOTAL VOLUME OF INPUT ELEMENTS = 2.508

********* ********* *********

LAMINAR SKIN FRICTION **VERTICAL TAIL**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	Q/Q INF	CONTROL DATA IMPACT / ISHAD	ETAC / ENPM	IMPACT / ISHADI	DELTA E
5.00	0.00083	0.00000	0.00083	0.0	0.00007	2.00000	1	1.0000	0	0.0
0.0	0.00000	0.00009	0.0	0.0	0.0	0.69000	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.00037	0.00000	0.00037	0.0	0.00005	2.00000	1	1.0000	0	0.0
0.0	0.00000	0.00004	0.0	0.0	0.0	0.31000	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.00009	0.0	0.00009	0.0	0.00002	2.00000	1	1.0000	0	0.0
0.0	0.0	0.00001	0.0	0.0	0.0	0.07500	1	1.0000	0	
	0.0	0.00000	-0.00000							
12.00	0.00005	-0.00000	0.00005	0.0	0.00001	2.00000	1	1.0000	0	0.0
0.0	-0.00000	0.00000	0.0	0.0	0.0	0.04100	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00001	0.00000	0.00001	0.0	0.00000	2.00000	1	1.0000	0	0.0
0.0	0.00000	0.00000	0.0	0.0	0.0	0.01100	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.00001	0.00000	0.00001	0.0	0.00000	2.00000	1	1.0000	0	0.0
0.0	0.00000	0.00000	0.0	0.0	0.0	0.01100	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA HAVE BEEN SAVED FOR SUMMATION

INVISCID PLUS LAMINAR SKIN FRICTION

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA ALPHA / BETA	C D / L/D / CY B	C L / C M / CLN B	C A / C LL / CLL B	C Y / C LN	C N / C F	K / Q/Q INF	CONTROL DATA IMPACT / ISHAD	ETAC / ENPM	IMPACI / ISHADI	DELTA E
5.00	0.01723	0.01777	0.01562	0.0	0.01920	2.00000	1	1.0000	0	0.0
0.0	1.03102	-0.00035	0.0	0.0	0.0	0.69000	1	1.0000	0	
	0.0	0.0	0.0							
7.00	0.01990	0.04284	0.01453	0.0	0.04495	2.00000	1	1.0000	0	0.0
0.0	2.15320	-0.00046	0.0	0.0	0.0	0.31000	1	1.0000	0	
	0.0	0.0	0.0							
10.00	0.02994	0.08495	0.01473	0.0	0.08886	2.00000	1	1.0000	0	0.0
0.0	2.83762	-0.00079	0.0	0.0	0.0	0.07500	1	1.0000	0	
	-0.00501	-0.00044	-0.00012							
12.00	0.04116	0.11803	0.01558	0.0	0.12402	2.00000	1	1.0000	0	0.0
0.0	2.86755	-0.00150	0.0	0.0	0.0	0.04100	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.06396	0.17162	0.01736	0.0	0.18233	2.00000	1	1.0000	0	0.0
0.0	2.68321	-0.00312	0.0	0.0	0.0	0.01100	1	1.0000	0	
	0.0	0.0	0.0							
15.00	0.07134	0.18535	0.02094	0.0	0.19750	2.00000	1	1.0000	0	10.00
0.0	2.59807	-0.00867	0.0	0.0	0.0	0.01100	1	1.0000	0	
	0.0	0.0	0.0							

THESE DATA ARE THE SUMMATION OF 12 COMPONENTS PREVIOUSLY SAVED

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 23.448 TOTAL NUMBER OF ELEMENTS = 1
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 37.448 TOTAL NUMBER OF ELEMENTS = 2
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 79.111 TOTAL NUMBER OF ELEMENTS = 3
TOTAL VOLUME OF INPUT ELEMENTS = 0.0

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 96.832 TOTAL NUMBER OF ELEMENTS = 4
TOTAL VOLUME OF INPUT ELEMENTS = 66.364

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 113.186 TOTAL NUMBER OF ELEMENTS = 5
TOTAL VOLUME OF INPUT ELEMENTS = 71.084

********* ***-***** *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 139.049 TOTAL NUMBER OF ELEMENTS = 6
TOTAL VOLUME OF INPUT ELEMENTS = 82.085

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 169.158 TOTAL NUMBER OF ELEMENTS = 7
TOTAL VOLUME OF INPUT ELEMENTS = 125.153

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 205.999 TOTAL NUMBER OF ELEMENTS = 8
TOTAL VOLUME OF INPUT ELEMENTS = 196.164

********* ********* *********

SECTION =SF TOTAL AREA OF INPUT ELEMENTS = 230.655 TOTAL NUMBER OF ELEMENTS = 9
TOTAL VOLUME OF INPUT ELEMENTS = 196.164

********* ********* *********

INDUCED PRESSURES ***BODY SURFACES**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K H/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACT ISHADT	DELTA E
5.00 0.0	0.00144 0.75803 0.0	0.00109 -0.00003 0.0	0.00134 0.0 0.0	0.0 0.0	0.00121 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
7.00 0.0	0.00151 1.14988 0.0	0.00174 -0.00010 0.0	0.00129 0.0 0.0	0.0 0.0	0.00191 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
10.00 0.0	0.00165 1.52469 -0.00019	0.00252 -0.00019 -0.00004	0.00119 0.0 0.00001	0.0 0.0	0.00277 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
12.00 0.0	0.00176 1.66743 0.0	0.00293 -0.00023 0.0	0.00111 0.0 0.0	0.0 0.0	0.00323 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00195 1.79156 0.0	0.00350 -0.00027 0.0	0.00098 0.0 0.0	0.0 0.0	0.00388 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00195 1.78781 0.0	0.00348 -0.00026 0.0	0.00098 0.0 0.0	0.0 0.0	0.00387 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	10.00

THESE DATA HAVE BEEN SAVED FOR SUMMATION

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67

INVISCID - LAM. S.F. - BODY SURFACES INDUCED PRESSURES

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 30.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA F
5.00 0.0	0.01867 1.00999 0.0	0.01886 -0.00038 0.0	0.01696 0.0 0.0	0.0 0.0	0.02041 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
7.00 0.0	0.02141 2.08225 0.0	0.04458 -0.00056 0.0	0.01582 0.0 0.0	0.0 0.0	0.04686 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
10.00 0.0	0.03159 2.76894 -0.00520	0.08747 -0.00098 -0.00048	0.01592 0.0 -0.00011	0.0 0.0	0.09163 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
12.00 0.0	0.04291 2.81845 0.0	0.12095 -0.00173 0.0	0.01668 0.0 0.0	0.0 0.0	0.12725 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.06591 2.65680 0.0	0.17512 -0.00339 0.0	0.01834 0.0 0.0	0.0 0.0	0.18621 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.07329 2.57653 0.0	0.18884 -0.00893 0.0	0.02192 0.0 0.0	0.0 0.0	0.20137 0.0	2.00000 1.00000	17 10	1.0000 1.0000	0 0	10.00

THESE DATA ARE THE SUMMATION OF 13 COMPONENTS PREVIOUSLY SAVED

SECTION = TOTAL AREA OF INPUT ELEMENTS = 15.111 TOTAL NUMBER OF ELEMENTS = 1
TOTAL VOLUME OF INPUT ELEMENTS = 2.508

********* ********* *********

HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
CASE 67

INDUCED PRESSURES **VERTICAL TAIL**

MACH= 19.084 VEL= 19999.9 FT/SEC RE/FT = 0.31157E 05
ALT = 200000.

S REF = 152.00 SPAN = 8.30 MAC = 33.00
X CG = -18.60 Y CG = 0.0 Z CG = 1.00

FORCE DATA / CONTROL DATA

ALPHA BETA	C D L/D CY B	C L C M CLN B	C A C LL CLL B	C Y C LN	C N C F	K Q/Q INF	IMPACT ISHAD	ETAC ENPM	IMPACI ISHADI	DELTA F
5.00 0.0	0.00000 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0	0.0 0.0	2.00000 0.69000	17 10	1.0000 1.0000	0 0	0.0
7.00 0.0	0.00000 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0	0.0 0.0	2.00000 0.31000	17 10	1.0000 1.0000	0 0	0.0
10.00 0.0	0.00000 0.0 -0.00001	0.0 0.0 0.00001	0.0 0.0 -0.00001	0.0 0.0	0.0 0.0	2.00000 0.07500	17 10	1.0000 1.0000	0 0	0.0
12.00 0.0	0.00000 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0	0.0 0.0	2.00000 0.04100	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00000 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0	0.0 0.0	2.00000 0.01100	17 10	1.0000 1.0000	0 0	0.0
15.00 0.0	0.00000 0.0 0.0	0.0 0.0 0.0	0.0 0.0 0.0	0.0 0.0	0.0 0.0	2.00000 0.01100	17 10	1.0000 1.0000	0 0	10.00

THESE DATA HAVE BEEN SAVED FOR SUMMATION

```
HYPERSONIC ARBITRARY-BODY PROGRAM, MARK III MOD 0
  CASE   67                                                                                   PAGE   4?

INVISCID PLUS LAMINAR SKIN FRICTION PLUS INDUCED PRESSURES

  MACH=  19.084  VEL=  19999.9 FT/SEC  RE/FT =  0.31157E 05
  ALT = 200000.

  S REF =    152.00  SPAN =    8.30  MAC  =   33.00
  X CG  =    -18.60  Y CG =    0.0   Z CG =    1.00

FORCE DATA                                                                  CONTROL DATA
  ALPHA    C D        C L        C A       C Y        C N        K            IMPACT  ETAC    IMPACI  DELTA
  BETA     L/D        C M        C LL      C LN       C F        Q/Q INF      ISHAD   ENPM    ISHADI
           CY B       CLN B      CLL B

   5.00   0.01867    0.01886    0.01696   0.?        0.02041    2.00000        17    1.0000    0      0.0
   0.0    1.00994   -0.00038    0.0       0.0        0.0        0.69000        10    1.0000    0
          0.0        0.0        0.0

   7.00   0.02141    0.04458    0.01582   0.0        0.04686    2.00000        17    1.0000    0      0.0
   0.0    2.08215   -0.00056    0.0       0.0        0.0        0.31000        10    1.0000    0
          0.0        0.0        0.0

  10.00   0.03159    0.08747    0.01592   0.0        0.09163    2.00000        17    1.0000    0      0.0
   0.0    2.76885   -0.00098    0.0       0.0        0.0        0.07500        10    1.0000    0
         -0.00521   -0.00046   -0.00012

  12.00   0.04292    0.12095    0.01668   0.0        0.12725    2.00000        17    1.0000    0      0.0
   0.0    2.81839   -0.00173    0.0       0.0        0.0        0.04100        10    1.0000    0
          0.0        0.0        0.0

  15.00   0.06591    0.17512    0.01834   0.0        0.18621    2.00000        17    1.0000    0      0.0
   0.0    2.65676   -0.00339    0.0       0.0        0.0        0.01100        10    1.0000    0
          0.0        0.0        0.0

  15.00   0.07329    0.18884    0.02192   0.0        0.20137    2.00000        17    1.0000    0     10.00
   0.0    2.57650   -0.00893    0.0       0.0        0.0        0.01100        10    1.0000    0
          0.0        0.0        0.0

          THESE DATA ARE THE SUMMATION OF  14 COMPONENTS PREVIOUSLY SAVED

          THESE DATA HAVE BEEN SAVED FOR PLOTTING




******** MAIN PROGRAM NOW HAS CONTROL OF SYSTEM ********


***** GRAPHIC OPTION HAS CONTROL *****

         OUTPUT DATA PLOTTER PROGRAM WILL BE EXECUTED

                              TAPE 10 JUST INSTRUCTED ME TO READ   6 CARDS FROM TAPE 9

                                        I JUST READ   6 CARDS FROM TAPE 9

JUST FINISHED PLOTTING ALL SORTS OF GOODIES ON TAPE 16. IF ALL GOES WELL, YOU SHOULD GET SOME RESULTS FROM THE SC-4020.

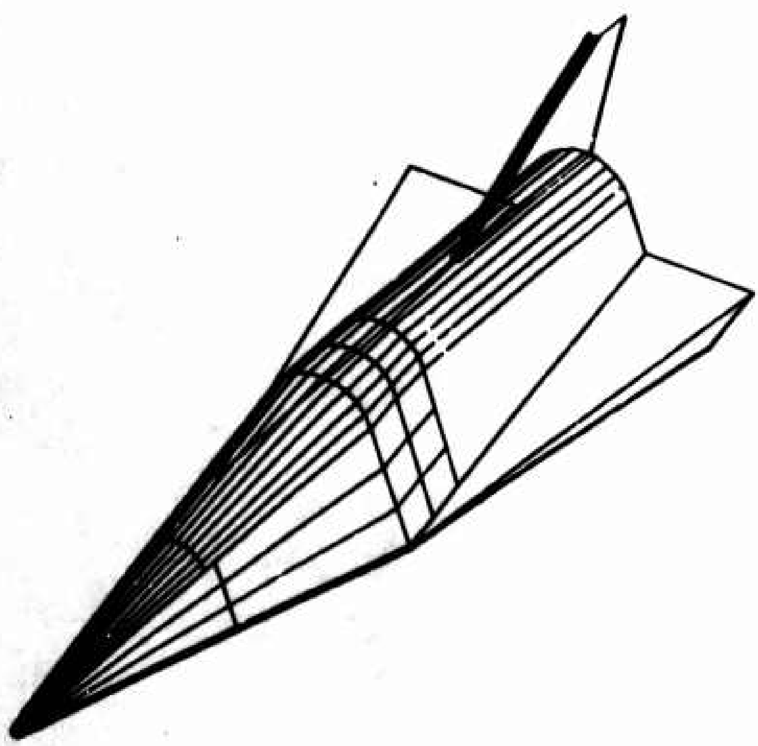



******** MAIN PROGRAM NOW HAS CONTROL OF SYSTEM ********

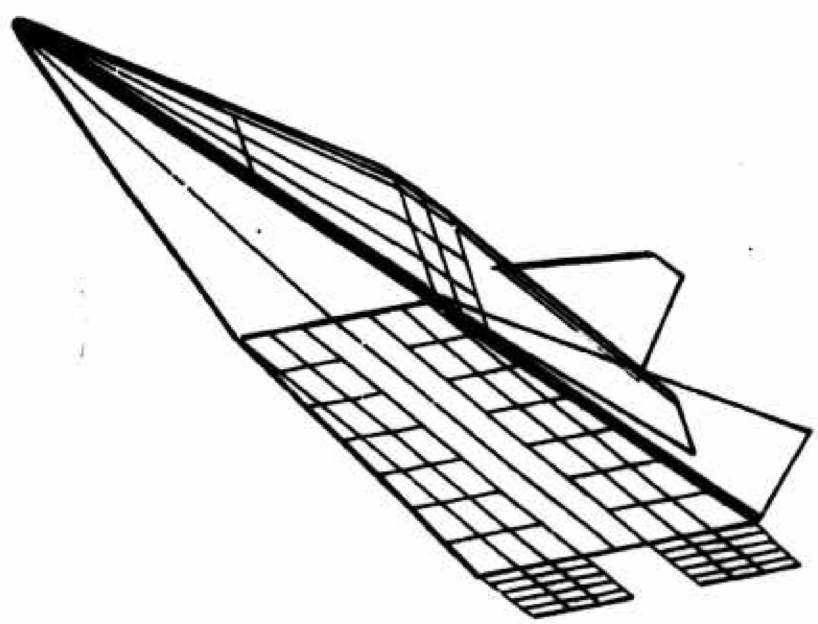
***** PROGRAM HAS REACHED NORMAL TERMINATION ******
```

HYPERSONIC ARBITRARY-BODY AERODYNAMIC PROGRAM
TYPICAL HIGH L/D VEHICLE -35, 25, -20

0001 0001

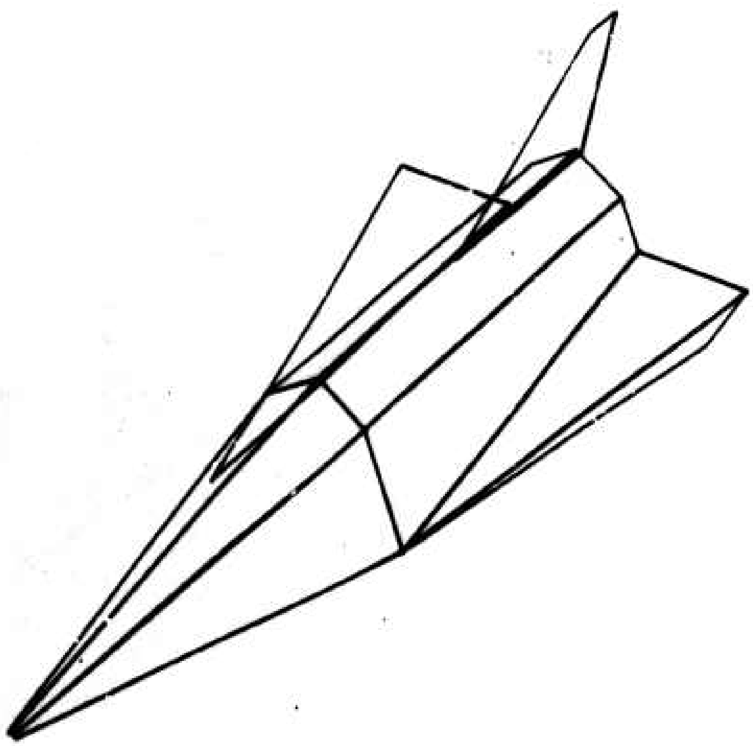


HYPERSONIC ARBITRARY-BODY AERODYNAMIC PROGRAM
TYPICAL HIGH L/D VEHICLE -35, -25, 10

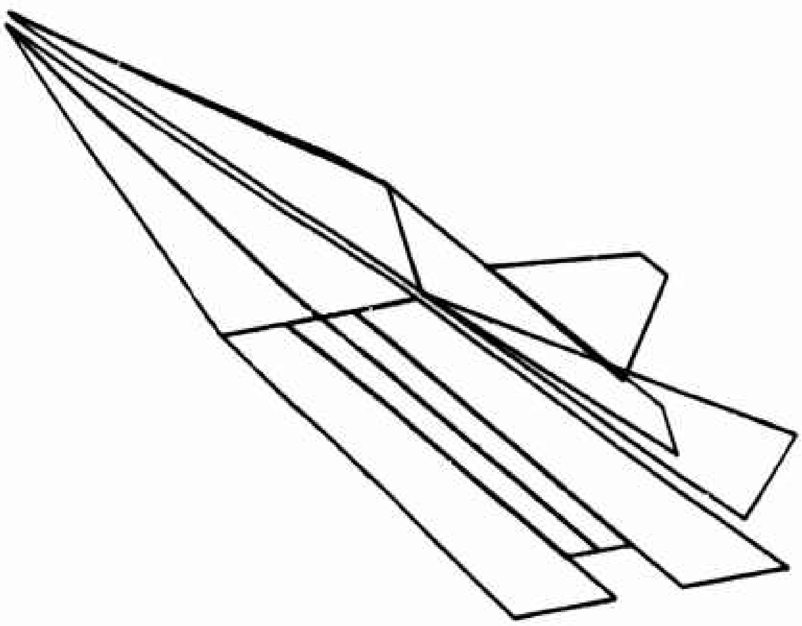


HYPERSONIC ARBITRARY-BODY AERODYNAMIC PROGRAM
TYPICAL HIGH L/D VEHICLE VISCOUS GEOMETRY -35, 25, -20

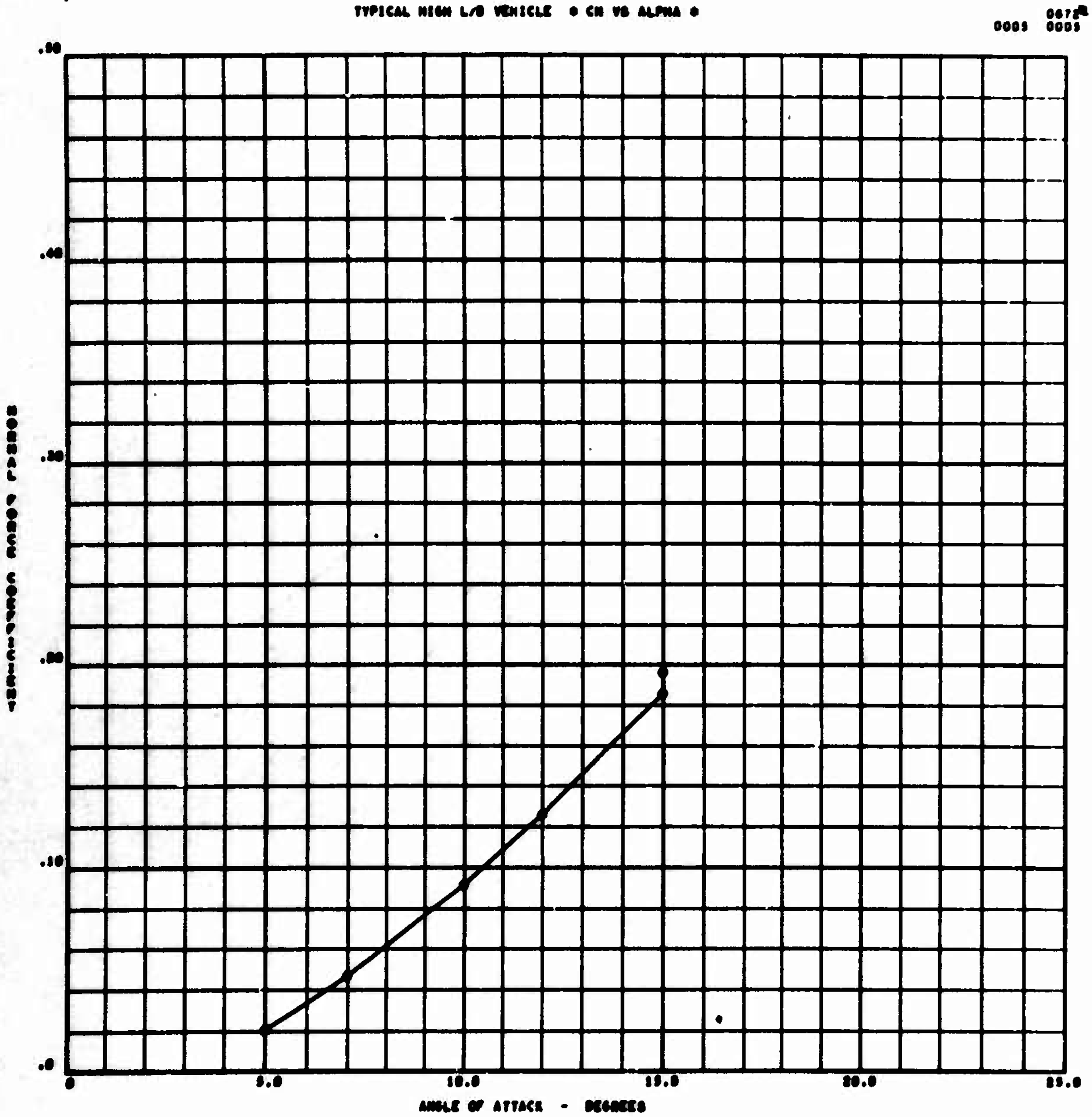
0672
0003 0003

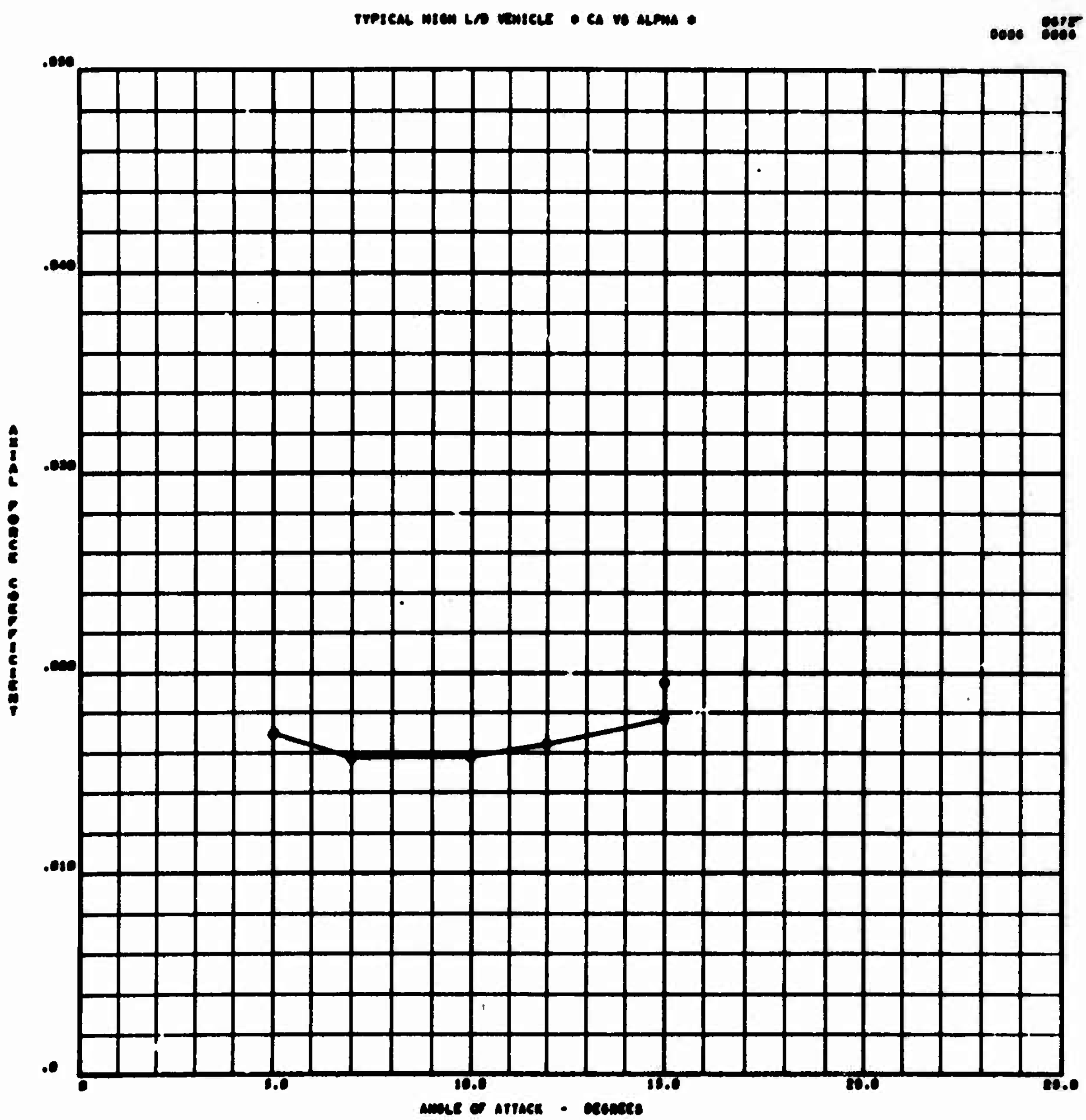


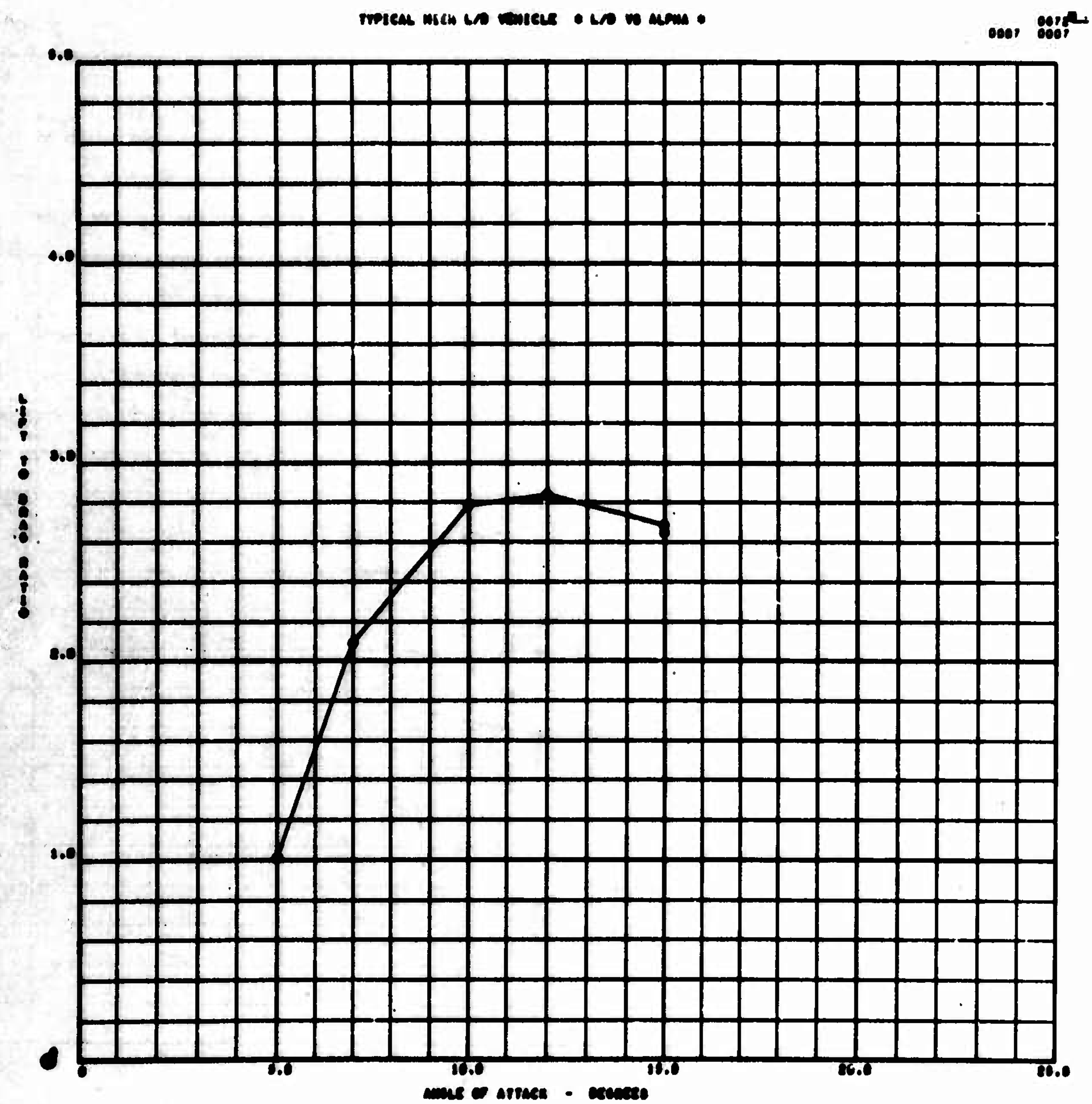
HYPERSONIC ARBITRARY-BODY AERODYNAMIC PROGRAM
TYPICAL HIGH L/D VEHICLE VISCOUS GEOMETRY -30, -25, 10 | 0004 0678 0004



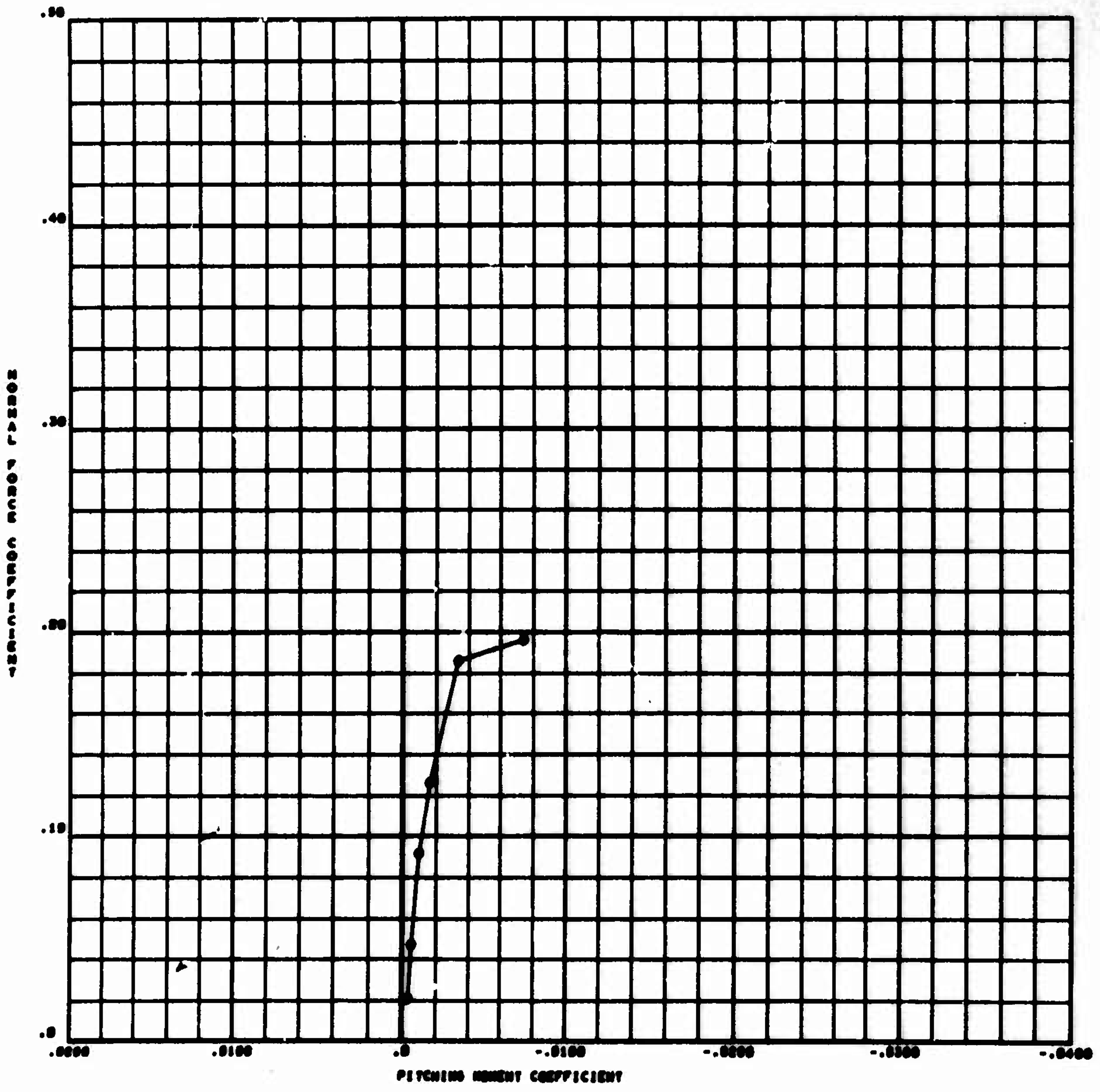
TYPICAL HIGH L/D VEHICLE * CN VS ALPHA *




TYPICAL HIGH L/D VEHICLE * CA VS ALPHA *
AXIAL FORCE COEFFICIENT
.050
.040
.030
.020
.010
.0
0
5.0
10.0
15.0
20.0
25.0
ANGLE OF ATTACK - DEGREES


TYPICAL HIGH L/D VEHICLE * L/D VS ALPHA *
LIFT TO DRAG RATIO
5.0
4.0
3.0
2.0
1.0
0
5.0
10.0
15.0
20.0
25.0
ANGLE OF ATTACK - DEGREES

TYPICAL HIGH L/D VEHICLE * CN VS CM *



APPENDIX C

SAMPLE INPUT SHEETS AND INPUT DATA CHARTS

This appendix contains samples of all the program input sheets and the input data charts. These sheets are printed on fold out-pages and located at the back of the report so that they may serve as a ready reference when reading the detailed program input instructions. These pages also contain very condensed versions of the input instructions. These condensed instructions should only be used as references by the experienced program user and should not be relied upon by someone new to the program.

This section of the report also contains input data charts for each of the major program phase options. These charts should also be folded out and used when studying the detailed input instructions.

ELEMENT DATA TITLE CARD (TYPE 1)

cc 60	ISUM	= 0	Don't Sum or Save	= 3	Sum, print, rewind
		= 1	Save data	= 4	Sum, print, backspace
		= 2	Sum, print, no rewind	= 5	Sum, print, rewind, write summation
cc 61	IREW8	= 0	No rewind	= 1	Rewind
cc 63	IPS	= 0	Don't save plotting data	= 1	Save plotting data for SC-4020
cc 64	IABDOT	= 0	No ȧ-ḃ cards	= 1	Input ȧ-ḃ cards
cc 65	IVECT	= 0	No thrust vector data cards	= 1	Input thrust vector data cards

ELEMENT DATA CONTROL CARD (TYPE 2)

cc 1	PRINTS	= 0	No print	= 1	Print element characteristics
cc 3	SYMFCT	= 0	(or =2) X-Z Plane symmetry	= 3	X-Z and X-Y Plane symmetry
		= 1	No symmetry		
cc 4	IORIEN	= 0	Normal mode	= 2	Skip 1st point in right row of each strip
		= 1	Streamwise strips	= 3	Skip 1st point in left row of each strip
cc 5	IFACT	= 0	No scale factors	= 1	Use scale factors
cc 60	IGEOM	= 0	Surface elements	= 2	Parametric cubic
		= 1	Ellipse geometry	= 3	Dummy option
cc 61	ITAPE	= 0	Read tape 5 (normal mode)	= 3	Rewind 8, read 5, write on 8
		= 1	Rewind 8 and read 8	= 4	Read 5, write on 8
		= 2	Read tape 8	= 5	Do not read surface-element data
cc 62	IGTYPE	= 0	Geometry for pressures	= 2	Skin-friction geometry data
		= 1	Control surface data	= 3	All-movable control surface geometry data
cc 63	IELOV	= 0	Calculate quadrilaterals	= 1	Do not calculate quadrilaterals

FORCE DATA TITLE CARD (TYPE 8)

cc 60	IRETI	= 0	Flight Condition Card next	= 1	Element Data Title Card next

FLIGHT CONDITION CARD (TYPE 9)

cc 45	IPS	= 0	Don't save plotting data	= 1	Save plotting data for SC-4020
cc 48	ITYP13	= 0	No Type 13 cards	= 1	Type 13 cards input
cc 53	IABDOT	= 0	No ȧ-ḃ cards	= 1	Input ȧ-ḃ cards
cc 54	IVECT	= 0	No thrust vector data cards	= 1	Input thrust vector cards
cc 60	LAST	= 0	Element Data Title Card next	= 1	Force Data Title Card next
			(action after force calculations are completed)		
cc 61-62	NAB	=	Number of Flight Attitude Cards (max. of 20)		
cc 63	NOAB	= 0	Type 12 cards are input	= 1	Type 12 cards are not input (use previous set)
cc 64-65	NS	= 0	Number of skin-friction cards		

CENTER OF GRAVITY CARD (TYPE 10)

Must follow each Flight Condition Card

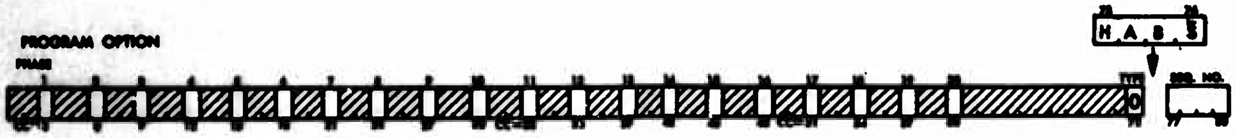
A

PAGE _____ OF _____

SHEET 1

HYPERSONIC ARBITRARY-BODY AERODYNAMIC COMPUTER PROGRAM SYSTEM
MARK III

SYSTEM CONTROL CARD



PROGRAM OPTIONS AVAILABLE (OPTIONS MAY BE USED IN ANY ORDER)

OPTION 1 AERODYNAMIC PROGRAM
2 PICTURE DRAWING PROGRAM
3 OUTPUT DATA PLOTTER PROGRAM
4 SLAB DELTA GEOMETRY GENERATION
5 GEOMETRY CARD PUNCH PROGRAM

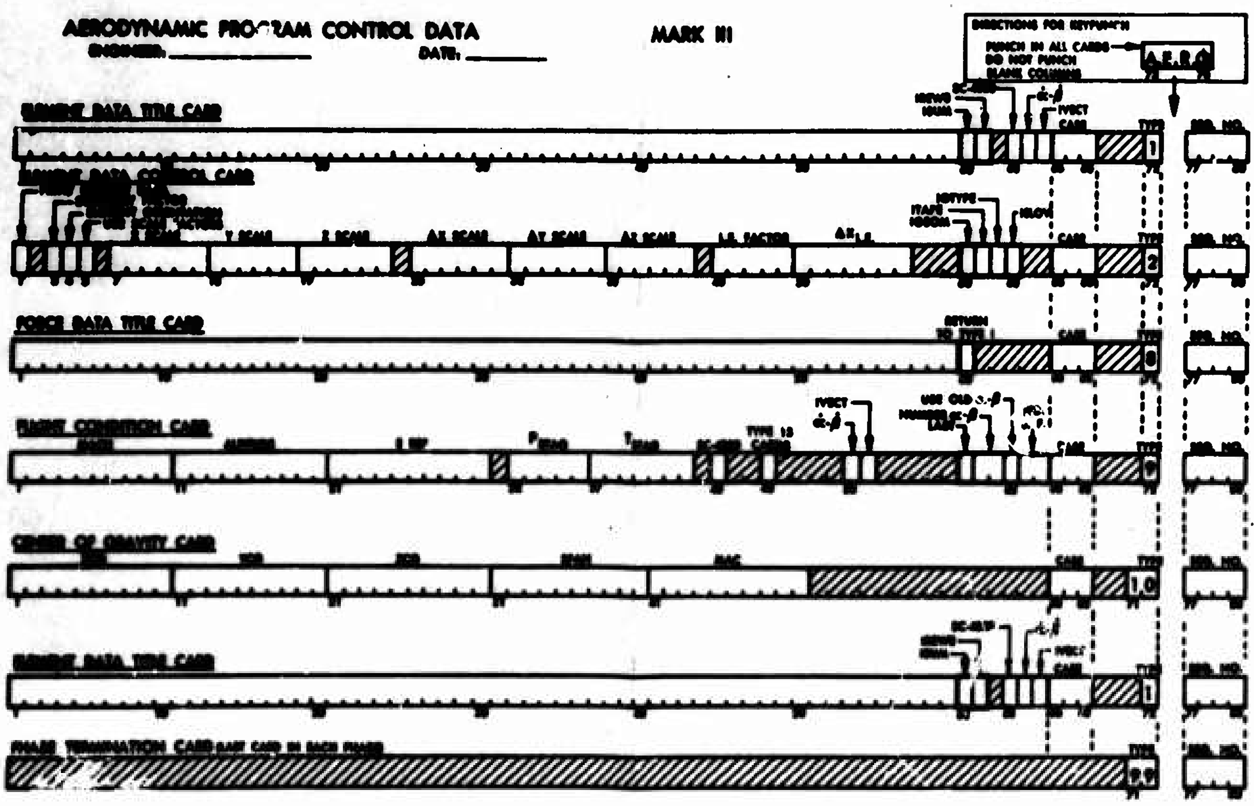
NOTE: THE LAST CARD IN EACH OPTION DECK SHOULD CONTAIN TYPE = 99

PAGE _____ OF _____

SHEET 2

AERODYNAMIC PROGRAM CONTROL DATA MARK III

ENGINEER __________ DATE _______



b

ELEMENT DATA CARD (TYPE 3)

cc 31	STATT	=2 First point of new section
		=1 First point of new n-line (except first n-line of section)
cc 62		=3 Last point of component or vehicle
		=0 All other points

ELLIPSE GENERATION CONTROL CARD (TYPE 4)

cc 60	DISCON	=0 θ_0 and θ_ℓ same for each section; =1 θ_ℓ same, θ_0 varies; =2 θ_0 same, θ_ℓ varies
cc 61	IPTINT	=0 Do not print data; =1 Print

ELLIPSE GENERATION DATA CARD (TYPE 5)

cc 60	LAST	=0 Not last cross-section, set STATT=0:
		=1 Last cross-section, set last STATT=0, write EOF, expect Force Title to return,
		=2 Last cross-section for section or component, set STATT=0, read new ellipse control card;
		=3 Last cross-section, set last STATT=3, write EOF, backspace to start of component;
		=4 Last cross-section, set last STATT=3, write EOF, don't backspace

A

PAGE ____ OF ___

SHEET 3

ELEMENT DATA

MARK III

ENGINEER: ____________

DATE: ____

VEHICLE COMPONENT ____________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS
DO NOT PUNCH
BLANK COLUMNS

3 AERO

±	X	±	Y	±	Z	STA/FL	±	X	±	Y	±	Z	STA/FL	SEQ. NO.

DIRECTIONS FOR KEYPUNCH: DO NOT PUNCH BLANK COLUMNS

NO UNDERPUNCHES IN SIGN FIELDS.

PAGE ____ OF ____

SHEET 4

ELLIPSE GENERATION DATA

MARK III

ENGINEER: ____________ DATE: ____

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS
DO NOT PUNCH
BLANK COLUMNS

AERO

ELLIPSE GENERATION CONTROL CARD

COMPONENT TITLE

ANGLE FLAG

4

SEQ. NO.

X-STATION	θ_o	θ_l	NO. θ	a	b	ΔZ	ΔY	LAST	5	SEQ. NO.

B

PARAMETRIC CUBIC TITLE CARD (TYPE 6)

cc 50→52	NOU	Number of elements in U direction
cc 54→56	NOW	Number of elements in W direction
cc 60	LAST	=0 Not last patch, set last STATT=0, read new patch data (no new title card); =1 Last patch, set last STATT=0, write EOF, return to surface data routine; =2 Not last patch, set last STATT=0, read new patch data (new title card next); =3 Last patch, set last STATT=3, write EOF on Tape 8, backspace =4 Last patch, set last STATT=3, write EOF on Tape 8, don't backspace
cc 61	ISOVR	=0 Status flag set by last in cc 60; =1 Last STATT=0 regardless of Last in cc 60
cc 62	IPRINT	=0, do not print data; =1, print

PARAMETRIC CUBIC BOUNDARY DATA (TYPE 7)

cc 31 cc 62	STATT	=2 First point of new patch =1 First point of boundaries 2, 3 and 4 =3 Last point of boundary 4 =0 All other points

SKIN FRICTION DATA CARD (TYPE 11)

cc 1-2	$IS_{I,1}$	= 1 to 10, Surface number
cc 3	$IS_{I,2}$	= 0 Oblique shock = 1 Tangent-cone
cc 4	$IS_{I,3}$	= 1 Upper surface } Oblique shock or tangent-cone in = 2 Lower surface } compression and Prandtl-Meyer in expansion = 3 Upper surface } Oblique shock or tangent-cone in compression = 4 Lower surface } and Newtonian + Prandtl-Meyer in expansion = 5 Upper surface } Newtonian + Prandtl-Meyer in both = 6 Lower surface } compression and expansion
cc 5	$IS_{I,4}$	= 0 Use turbulent skin-friction data in summation with pressure forces = 1 Use laminar skin-friction data in summation with pressure forces
cc 6	$IS_{I,5}$	= 0 Use α (Mode 2 only) = 1 Don't use α (Mode 2 only)
cc 7	$IS_{I,6}$	= 0, 3, 6, 8 Calculate equilibrium wall temperature = 1, 4 Set wall temperature to adiabatic wall temperature = 2, 5, 7, 9 Use input wall temperature
cc 8	$IS_{I,7}$	= 0 Do not print average skin-friction data = 1 Print (recommended option)
cc 9	$IS_{I,8}$	= 0 Do not print flow characteristics = 1 Print flow characteristics (recommended option)
cc 10	$IS_{I,9}$	= 0 Do not print iteration or local skin-friction results = 1 Print iterations for wall temperature and final local skin-friction data = 2 Print final local skin-friction data

PAGE ____ OF ____

SHEET 5

PARAMETRIC CUBIC PATCH DATA

MARK III

ENGINEER: ______________ DATE: ______

DIRECTIONS FOR KEYPUNCH	CASE	SECT.	
PUNCH IN ALL CARDS →			AERO
DO NOT PUNCH BLANK COLUMNS			

PARAMETRIC CUBIC TITLE CARD

	NO. U	NO. W	LAST	MOVE	PRINT	TYPE	SEQ. NO.
						6	

PARAMETRIC CUBIC BOUNDARY DATA

	X		Y		Z	STATUS		X		Y		Z	STATUS	TYPE	SEQ. NO.
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														7	
														[illegible]	
														7	
														7	
														7	
														7	
														7	

DIRECTIONS FOR KEYPUNCH: DO NOT PUNCH BLANK COLUMNS   NO UNDERPUNCHES IN SIGN FIELDS.

PAGE ____ OF ____

SHEET 6

SKIN FRICTION DATA

MARK III

ENGINEER: ______________

DATE: ______________

DIRECTIONS FOR KEYPUNCH	CASE		TYPE	
PUNCH IN ALL CARDS →			1 1	AERO
DO NOT PUNCH BLANK COLUMNS				

SURFACE NUMBER							WETTED AREA	LENGTH ~ FT	INITIAL LENGTH ~ FT	INITIAL TAPER RATIO	TAPER RATIO	T_{Wall} ~ °R Lam	T_{Wall} ~ °R Turb	η_{C_T}	SEQ. NO.
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															

FLIGHT ATTITUDE CARD (TYPE 12)

cc 13-18 CPSTAG Modified Newtonian correlation factor (K)
cc 26-30 ETAC Prandtl-Meyer expansion correction factor (usually = 1.0)
cc 36-40 QQINF Dynamic pressure correction factor (usually = 1.0)
cc 41-42 IMPACT Impact pressure calculation method
- = 1 Modified Newtonian
- = 2 Modified Newtonian + Prandtl-Meyer
- = 3 Tangent-wedge (shock tables)
- = 4 Tangent-wedge empirical
- = 5 Tangent-cone
- = 6 OSU blunt-body empirical
- = 7 Van Dyke Unified
- = 8 Blunt-body skin friction
- = 9 Shock-expansion
- = 10 Free-molecular flow
- = 11 Input pressure coefficient
- = 12 Hankey flat-surface empirical
- = 13 Delta-wing empirical
- = 14 Dahlem-Buck empirical
- = 15 Blast wave
- = 16 Modified tangent-cone
- = 17 Boundary layer induced pressures

cc 43-44 ISHAD Shadow pressure calculation method
- = 1 Newtonian (C_p = 0)
- = 2 Modified Newtonian + Prandtl-Meyer
- = 3 Prandtl-Meyer from free-stream
- = 4 OSU blunt-body empirical
- = 5 Van Dyke Unified
- = 6 High-Mach base pressure ($C_p = -1/M^2$)
- = 7 Shock-expansion
- = 8 Input pressure coefficient
- = 9 Free-molecular flow
- = 10 Boundary-layer induced pressures

cc 45 IDERIV Derivative flag
- = 0 No stability derivatives
- = 1 α derivatives
- = 2 β derivatives
- = 3 (reserved for roll derivatives)
- = 4 Control-surface derivatives
- = 5 Dynamic derivatives in pitch
- = 6 Dynamic derivatives in yaw

cc 46 PRINT
- = 0 Do not print detailed element force contributions
- = 1 Print

cc 47 IPRINT
- = 0 Do not print detailed shock-expansion calculations
- = 1 Print (recommended option for at least one angle of attack)

cc 49-50 IMPACI Method to be used on 1st element for shock-expansion calculations (in compression)
- = 3 Tangent-wedge
- = 5 Tangent-cone
- = 13 Delta-wing empirical

cc 51-52 ISHADI Method to be used on 1st element for shock-expansion calculations (in expansion)
- = 3 Prandtl-Meyer expansion

FLIGHT ATTITUDE DATA **MARK III**

PAGE _____ OF _____
SHEET 7

ENGINEER: ____________________

DATE: ______

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE | ▨ | TYPE 1, 2 | A E R O
DO NOT PUNCH BLANK COLUMNS

	1 α	7 β	13 K	19 CRP	26 q_c	31 θ/θ_{BODY}	36 q/q_∞	[illegible]	53 δ_θ	58 R_{e_T}	63 T_{Wall}		77 SEQ. NO. 80
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													
20													

COEFFICIENT INCREMENT DATA **MARK III**

PAGE _____ OF _____
SHEET 8

ENGINEER: ____________________

DATE: ______

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE | ▨ | TYPE 1, 3 | A E R O
DO NOT PUNCH BLANK COLUMNS

	1 C_A	11 C_N	21 C_Y	31 C_ℓ	41 C_m	51 C_n	60	77 SEQ. NO. 80
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

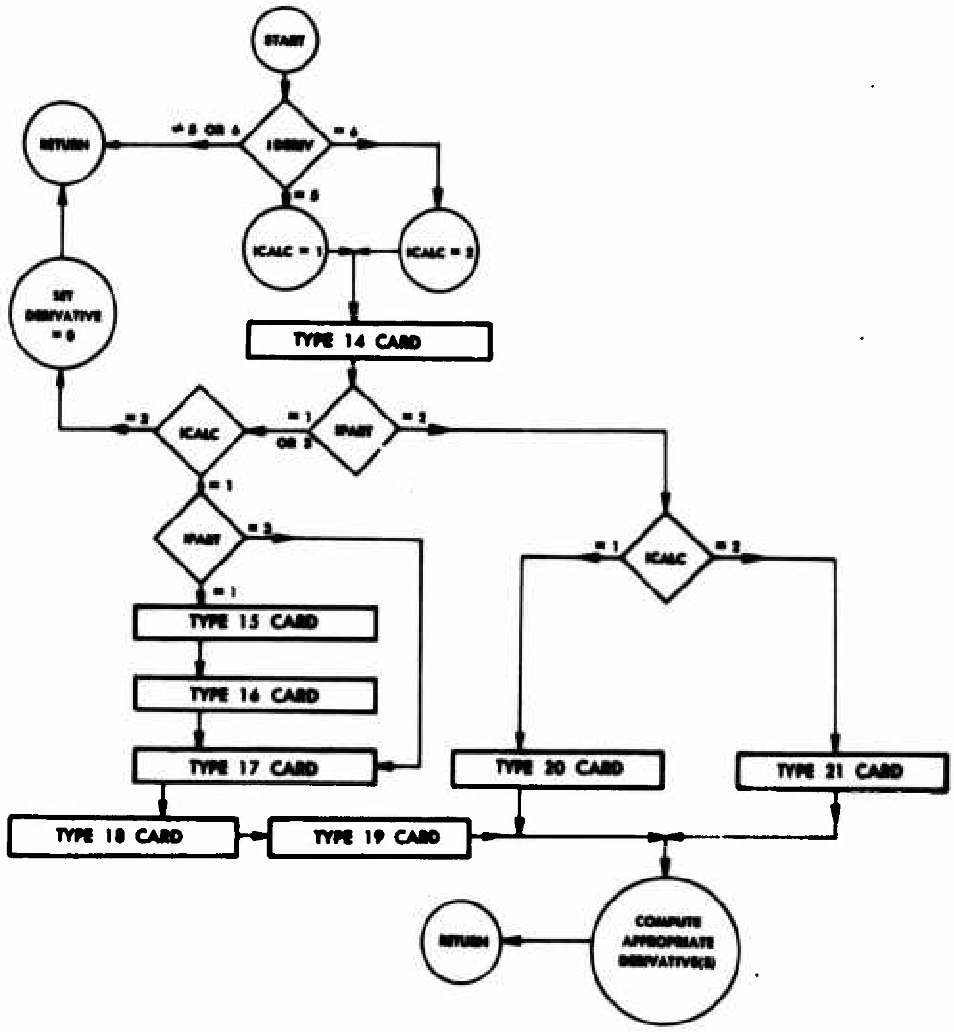
PLUNGE DERIVATIVE DATA

Type 14 Card

cc 1	IPART	=1 Wing	=2 Body	=3 Tail

Type 15 & 17 Card

cc 61	=1 K_{BW} input =3 Rectangle	=1 Slender body theory =4 Triangle	=2 Trapezoid =5 Trapezoid (no after body for wing)



THRUST VECTOR DATA CARD (TYPE 22)

cc 60	LAST	=0 Not the last vector card	=1 Last vector card
	IPRINT	=0 Do not print thrust vector data	=1 Print data

PLUNGE DERIVATIVE DATA MARK III

PAGE OF
SHEET 9

ENGINEER: ____________________
DATE: ____________________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE (68–69) | AERO (73–76)
DO NOT PUNCH BLANK COLUMNS

CONTROL CARD
I PART (= 1 WING = 2 BODY = 3 TAIL)

Group	Col. 1	11	21	31	41	51	61	TYPE (71)	SEQ. NO. (77–80)
CONTROL CARD	I PART							14	
WING	AR	LAMBDA	M	SWBYS	CWBYC	S	K	15	
WING	CR	B	BETA	CLALW	CMWFP	KBW		16	
TAIL	AR	LAMBDA	M	SWBYS	GAMMAT	S	K	17	
TAIL	CR	B	BETA	CLALW	UPWASH	XBTBYC		18	
TAIL	KBW	Q						19	
BODY	VOLUME	S FRONT	LENGTH	X_o	X_c	C		20	
BODY	VOLUME	S FRONT	B					21	

THRUST VECTOR DATA MARK III

PAGE ______ OF ____
SHEET 10

ENGINEER: ____________________
DATE: ________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS: CASE (68–69) | TYPE 22 (71) | AERO (73–76)
DO NOT PUNCH BLANK COLUMNS

F ~ lbs. (1)	X CENT (11)	Y CENT (17)	Z CENT (23)	N_x (29)	N_y (35)	N_z (41)	(47)	LAST (59)	PRINT (60)	SEQ. NO. (77–80)

ELEMENT DATA CONTROL CARD (TYPE 32)

cc 1	PRINTS	=0 Don't print element characteristics	=1 Print element characteristics
cc 3	SYMFCT	=1 No symmetry =2 X-Z plane symmetry	=3 X-Z and X-Y plane symmetry
cc 5	IFCT	=0 Use input geom	=1 Use scale factors
cc 62	ITAPE	=0 Read goem from tape 5	=1 Read geom from tape 8
cc 63	IREW8	=0 Rewind tape 8	=1 Don't rewind tape 8

VIEWING ANGLES CARD (TYPE 34)

cc 22	ICS	=0 Connect all points =2 Connect 1-4 and 2-3	=1 Connect 1-2 and 3-4 =3 Don't connect
cc 24	IREFL	=0 Don't plot reflection =2 Plot reflection (1 quadrent input)	=1 Plot reflection
cc 26	ISHAD	=0 Don't plot shadow	=1 Plot shadow
cc 28	IAREA	=0 Don't print section areas on SC=4020	=1 Print areas
cc 30	IQUAD	=0 Draw input elements	=1 Draw quadrilateral elements
cc 32	IFRAME	=0 Advance frame after all vehicle elements =2 Advance after each section	=1 Advance after each column
cc 34-35	NCAM	=9 Hard copy =0 Both	=35 35mm microfilm
cc 37-38	MARKPT	See Page 97	
cc 41→43	NG	Emphasize Nth Vertical grid	=+ Rectangular grid =0 No lines emphasized
cc 44→46	MG	Emphasize Mth Horizontal grid	=- Square grid =-0 When no grid is used
cc 48→50	IG	Label every Ith vertical grid line (=0 for no grid)	
cc 51→53	JG	Label every Jth horizontal grid line (=0 for no grid)	
cc 55-56	NXG	Number of characters in X-scale number labels (=0 for no grid)	
cc 57-58	NYG	Number of characters in Y-scale number labels (=0 for no grid)	
cc 60	LAST	=0 Not last plot for this geom	=1 Last plot for this geom

SCALES CARD (TYPE 35)

cc 60	NOSCAL	=0 Include grid lines and scales	=1 No grid

DATA SOURCE CONTROL CARD (TYPE 41)

cc 1→4	NC	=0 Read from tapes 10 & 9 =1 No plotted data	=NC Read NC data sets from 5

PLOT CONTROL ARRAY CARD (TYPE 47)

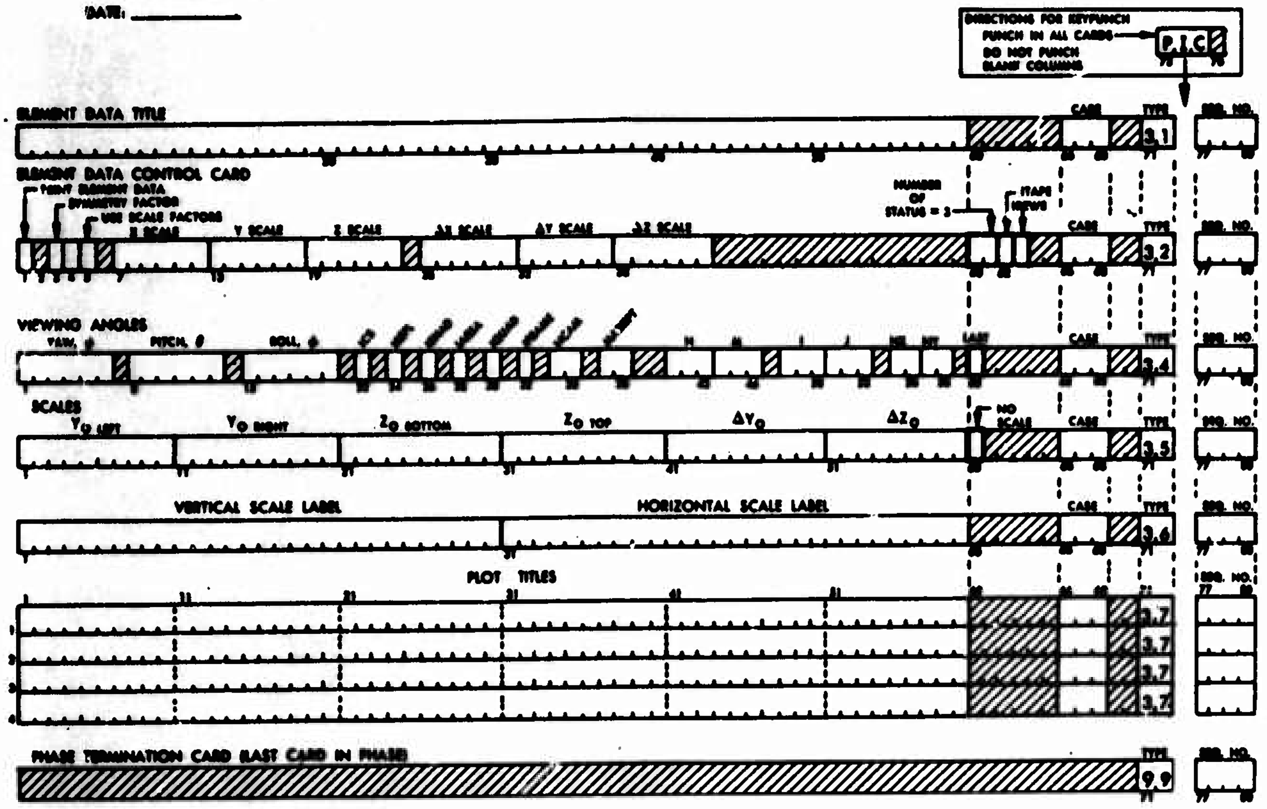
cc 1-2	I_1	= Data Id for x scale	=1; α =4, C_A =7, β =10, C_ℓ =2 C_D =5, C_Y =8, L/D =11, C_n =3 C_L =6, C_N =9, C_m =12, C_f
cc 3-4	I_2	=Data Id for y scale	
cc 6	I_3	=1 Advance film, show frame count =3 Advance, no frame count	=2 No advance
cc 8→10	I_4	±N Emphasize every Nth vertical line	-= Square grid += Rectangular grid 0= Emphasize no lines
cc 11→13	I_5	±M emphasize every Mth horizontal line	
cc 15→17	I_6	±I label every Ith grid line	+= Numerical labels at 0 axis
cc 18→20	I_7	±J label every Jth grid line	-= Numerical labels outside grid
cc 22→25	I_8	Number of points to be plotted	
cc 27→29	I_9	X array -plot every I_9th data point (=1, plot all data points)	
cc 30→32	I_{10}	Y array -plot every I_{10}th data point (=1, plot all data points)	
cc 34→36	I_{11}	Number of plotting characters	
cc 38→39	I_{12}	Plotting symbol code (see page 97)	
cc 41	I_{13}	=0 Do not connect plotted points	=1 Connect plotted points
cc 43, 44	I_{14}	Camera =9 Hard copy =0 Both	=35, 35mm microfilm
cc 46	I_{15}	=0 Stop after plotting this x-y data =2 Return to read type 41 =4 Read tape 1	=1 Return to read type 44→47 cards =3 Return to read tape 10
cc 48,49	I_{16}	X scale max no. of characters in number labels,	
cc 50,51	I_{17}	Y scale include decimal point, +=F format, -=E format	
cc 53,54	I_{18}	Number of type 48 cards (max of 64)	
cc 56	I_{19}	=0 Do not write arrays on tape 1	=1 Write arrays on tape 1
cc 58,59	I_{20}	Number of blocks of data to be plotted with same type 44, 45 & 46 cards	
cc 61	I_{21}	On I_{21}th block of data, $I_{15} = I_{21}$	

PICTURE DRAWING PROGRAM DATA **MARK III** PAGE ____ OF ____

SHEET 11

ENGINEER: ____________________

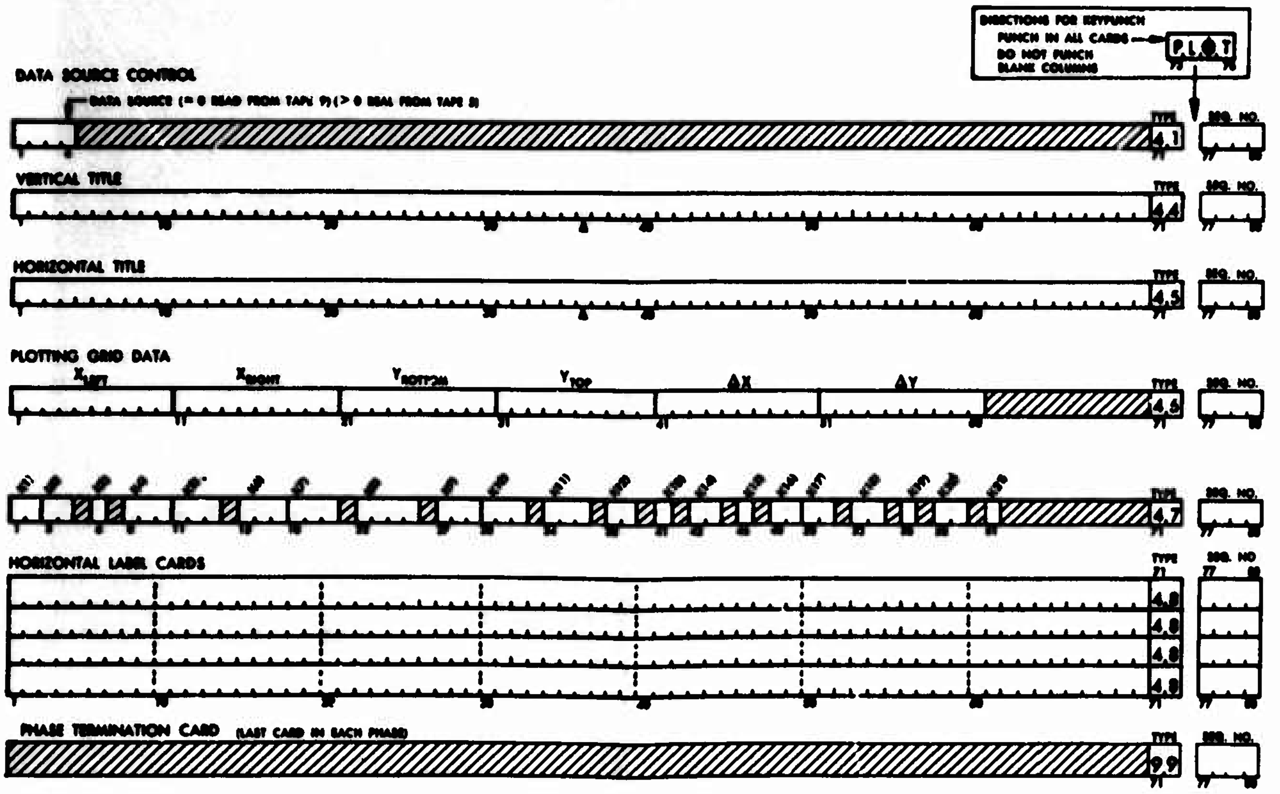
DATE: __________



PLOTTER PROGRAM CONTROL DATA **MARK III** PAGE ____ OF ____

SHEET 12

ENGINEER: ____________________ DATE: __________



SLAB DELTA TITLE CARD (TYPE 50)

cc 60	LAST	Termination flag; =0 Not the last slab delta configuration =1 Last slab delta completed

SLAB DELTA SWEEP CARD (TYPE 51)

cc 21→23	THETAB	Number of $\Delta\theta$ for lower 90^0 of the leading edge
cc 24→26	THETAT	Number of $\Delta\theta$ for top 90^0 of the leading edge
cc 27→29	NOSPAN	Number of element divisions to be generated
cc 30	ITOC	=0 Thickness tables not input =1 Input tables
cc 31	MODE	=1, geometry for top inboard leading edge not generated =2, basic slab delta with straight sides if thickness factors are used =3, elliptical top if thickness factors are used
cc 36	IREW8	=0 Rewind tape 8 =1 Do not rewind 8
cc 42	I8BSP	=0 Do not backspace tape 8 =1 Backspace 8 according to the data on 8
cc 48	IPRINT	=0 Do not print generated element card images =1 Print card images

SLAB DELTA STATION DATA CARD (TYPE 54)

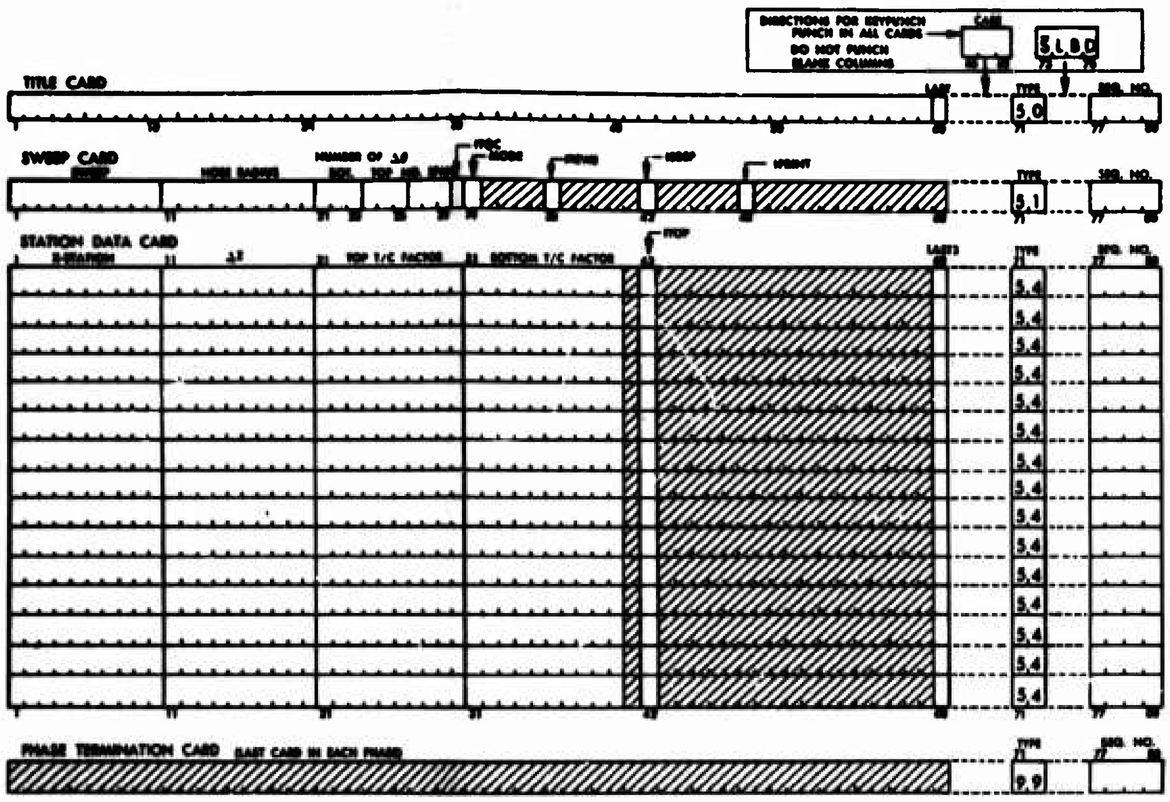
cc 42	ITOP	=0 Flat top included =1 Flat top not generated
cc 60	LAST	=0 Not the last cross-section =1 Last cross-section, last cross-section, set last point status flag =3

SLAB DELTA GEOMETRY DATA　　MARK III

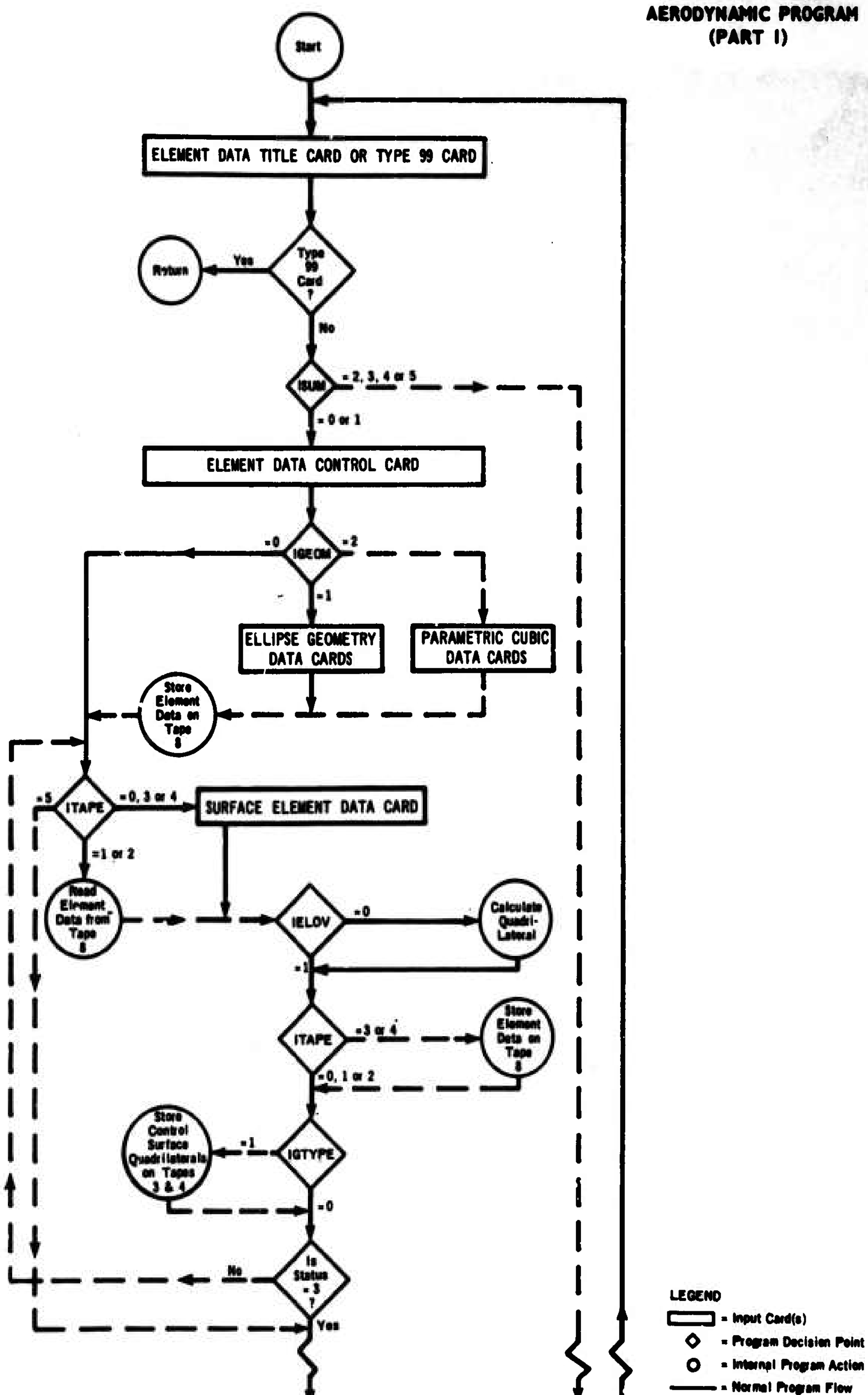
ENGINEER: ______________ DATE: ________

PAGE ____ OF ____

SHEET 13

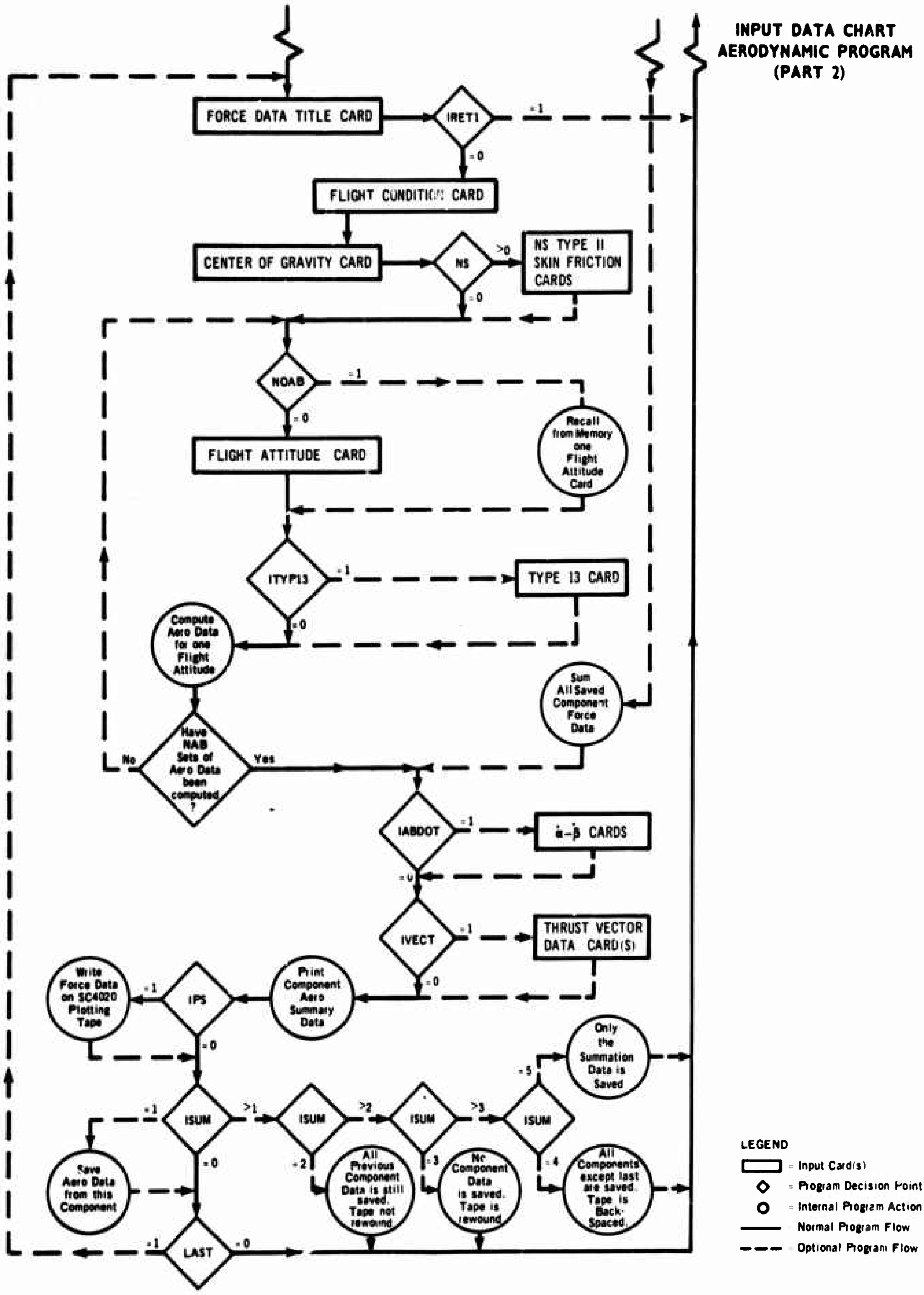


INPUT DATA CHART
AERODYNAMIC PROGRAM
(PART I)

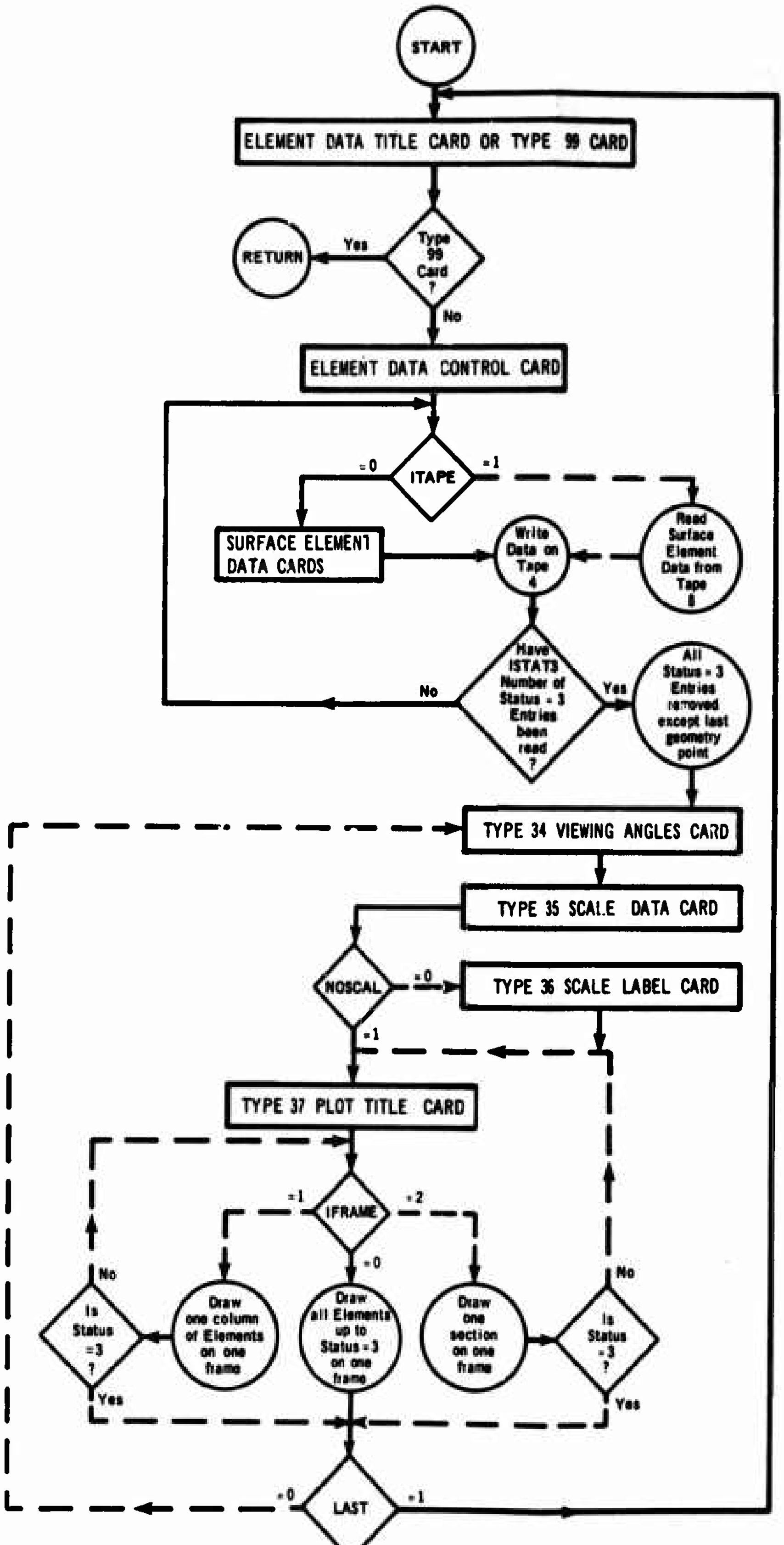


(CONTINUED ON NEXT PAGE)

INPUT DATA CHART
AERODYNAMIC PROGRAM
(PART 2)

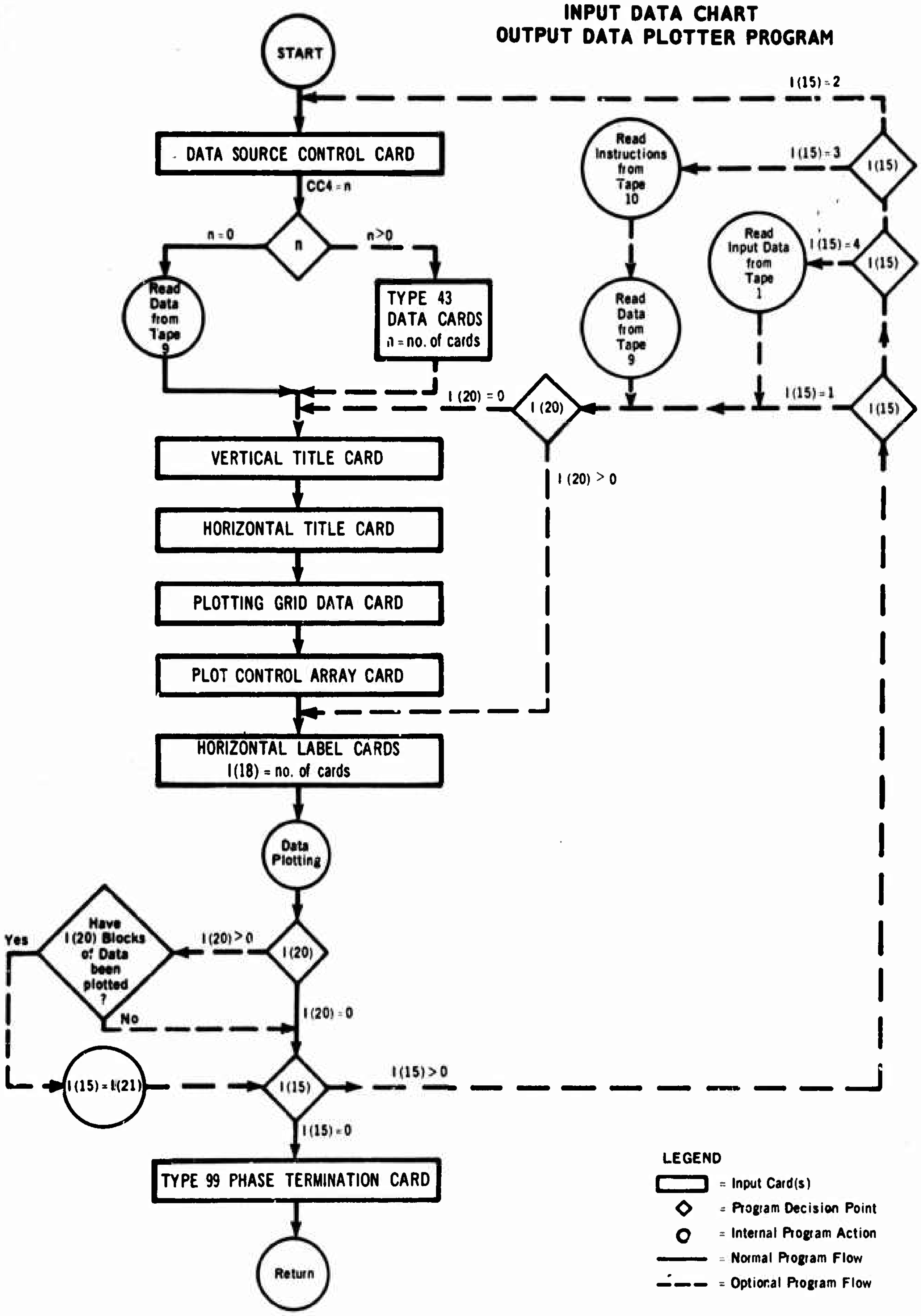


INPUT DATA CHART
PICTURE DRAWING PROGRAM

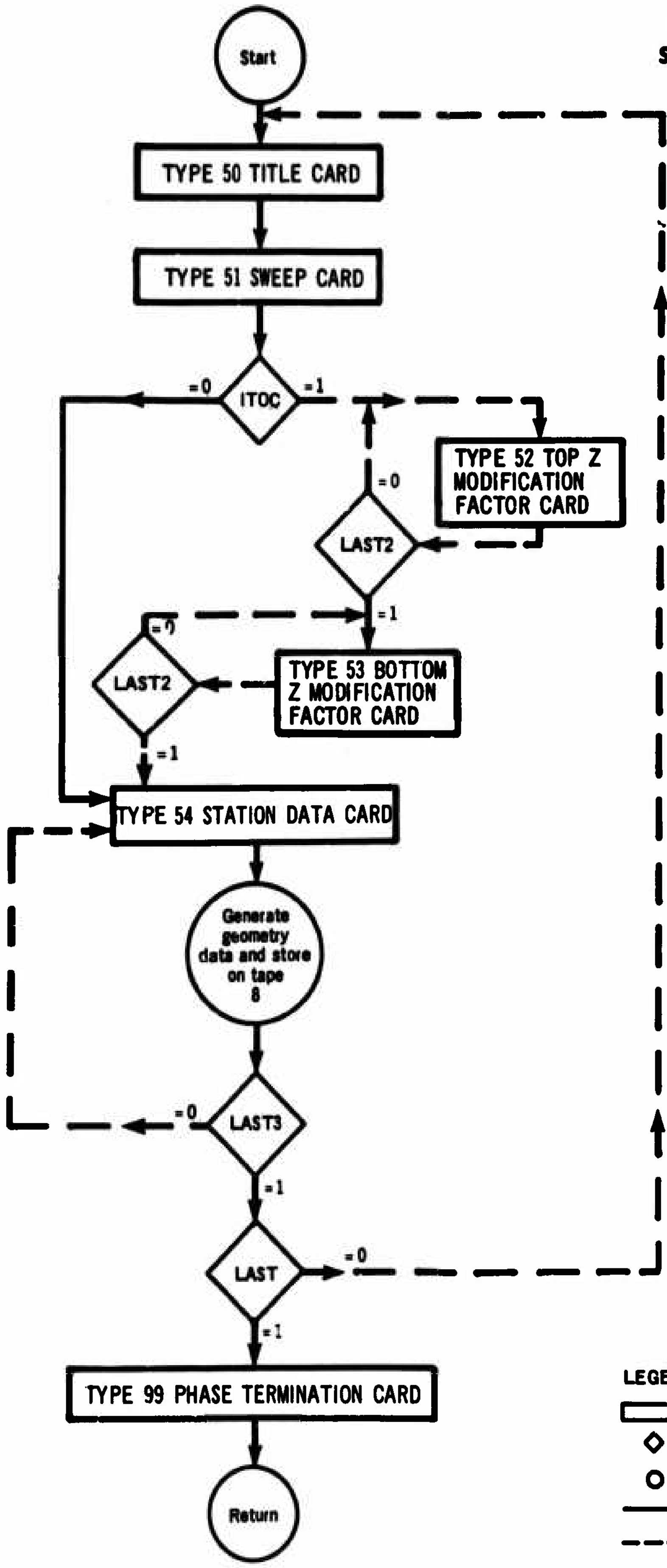


LEGEND
- ▭ = Input Card(s)
- ◇ = Program Decision Point
- ○ = Internal Program Action
- ——— = Normal Program Flow
- – – – = Optional Program Flow

INPUT DATA CHART
OUTPUT DATA PLOTTER PROGRAM



INPUT DATA CHART
SLAB DELTA PROGRAM



LEGEND
- = Input Card(s)
- = Program Decision Point
- = Internal Program Action
- = Normal Program Flow
- = Optional Program Flow

APPENDIX D

USER'S KIT

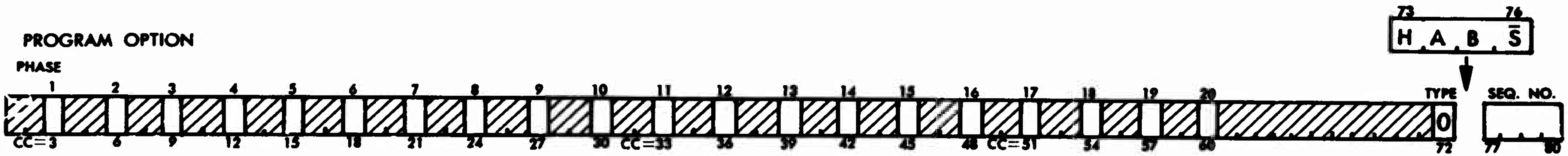
This Appendix contains a complete set of all the program input sheets.

PAGE ______ OF ______

SHEET 1

HYPERSONIC ARBITRARY-BODY AERODYNAMIC COMPUTER PROGRAM SYSTEM
MARK III

SYSTEM CONTROL CARD



PROGRAM OPTIONS AVAILABLE (OPTIONS MAY BE USED IN ANY ORDER)

OPTION 1 AERODYNAMIC PROGRAM
2 PICTURE DRAWING PROGRAM
3 OUTPUT DATA PLOTTER PROGRAM
4 SLAB DELTA GEOMETRY GENERATION
5 GEOMETRY CARD PUNCH PROGRAM

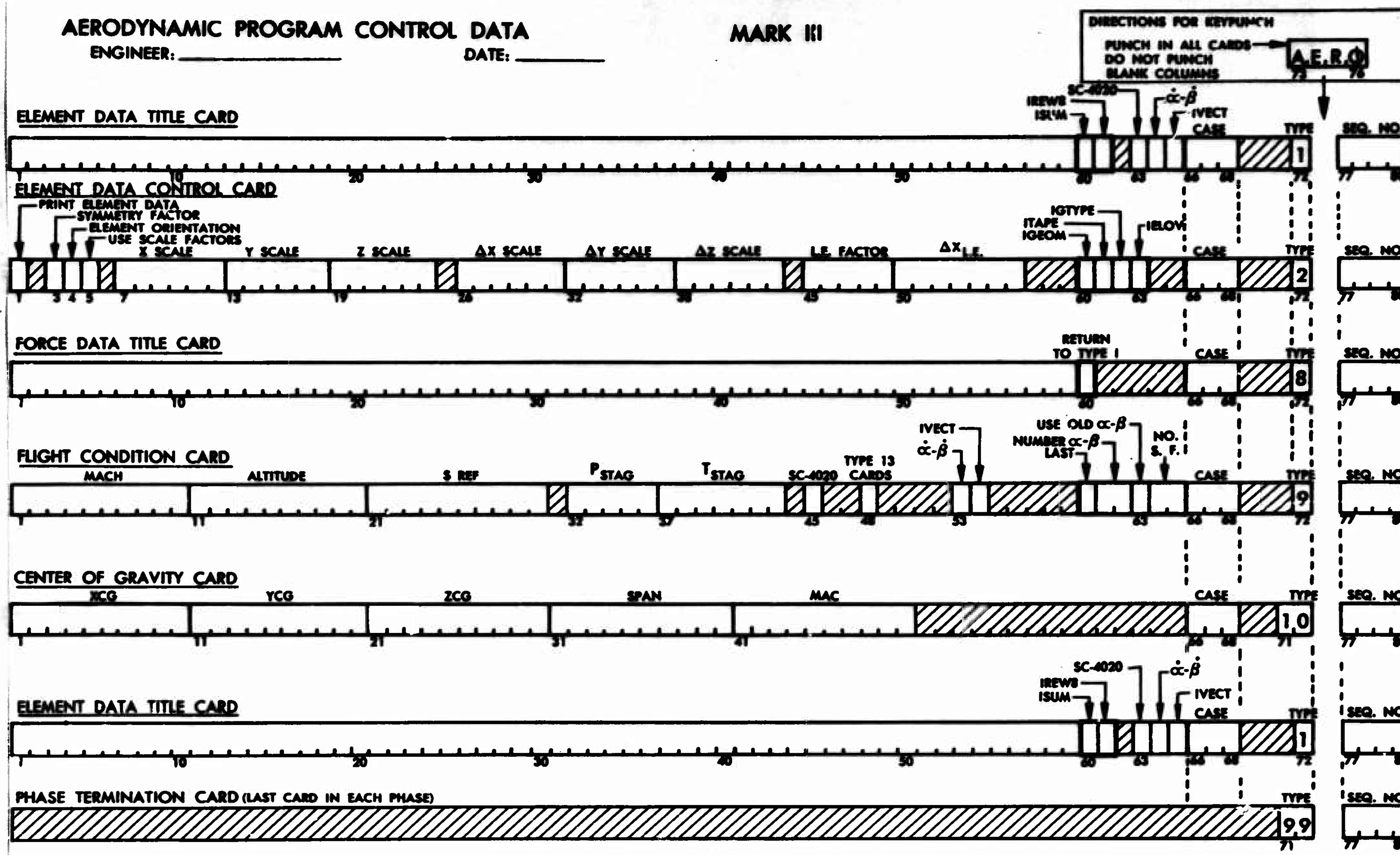
NOTE: THE LAST CARD IN EACH OPTION DECK SHOULD CONTAIN TYPE = 99

PAGE ______ OF ______
SHEET 2

AERODYNAMIC PROGRAM CONTROL DATA

ENGINEER: ______________ DATE: ______________

MARK III



PAGE ____ OF ____

SHEET 3

ELEMENT DATA

MARK III

ENGINEER: ____________________

DATE: ______

VEHICLE COMPONENT ____________________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE (66) SECT. (70) TYPE (72) 3 AE,R,Φ (76)
DO NOT PUNCH BLANK COLUMNS

±	X	±	Y	±	Z	STATUS	±	X	±	Y	±	Z	STATUS	SEQ. NO.
1	2 3 4 5 6 7 8 9 10	11	12 13 14 15 16 17 18 19 20	21	22 23 24 25 26 27 28 29 30	31	32	33 34 35 36 37 38 39 40 41	42	43 44 45 46 47 48 49 50 51	52	53 54 55 56 57 58 59 60 61	62	77 78 79 80

DIRECTIONS FOR KEYPUNCH: DO NOT PUNCH BLANK COLUMNS

NO UNDERPUNCHES IN SIGN FIELDS.

PAGE ______ OF ______

SHEET 4

ELLIPSE GENERATION DATA

MARK III

ENGINEER: ______________________ DATE: ________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS — CASE (66–69) SECT (70) ΑΕRΦ (73–76)
DO NOT PUNCH BLANK COLUMNS

ELLIPSE GENERATION CONTROL CARD

COMPONENT TITLE (1–50)	ANGLE FLAG (60)	PRINT	TYPE	SEQ. NO. (77–80)
			4	

X-STATION (1)	θ_o (11)	θ_l (17)	NO. θ (25)	a (26)	b (36)	ΔZ (46)	ΔY (53)	LAST (60)	TYPE (72)	SEQ. NO. (77–80)
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	
									5	

PAGE ____ ____

SHEET 5

PARAMETRIC CUBIC PATCH DATA

MARK III

ENGINEER: ______________ DATE: ______

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE (66–68) SECT. (70)
DO NOT PUNCH BLANK COLUMNS

AERO (73–76)

PARAMETRIC CUBIC TITLE CARD

1–50	NO. U (52)	NO. W (56)	LAST (60)	ISOVR	PRINT (62)	TYPE (72)	SEQ. NO. (77–80)
						6	

PARAMETRIC CUBIC BOUNDARY DATA

±	X	±	Y	±	Z	STATUS	±	X	±	Y	±	Z	STATUS	TYPE	SEQ. NO.
1	2 3 4 5 6 7 8 9 10	11	12 13 14 15 16 17 18 19 20	21	22 23 24 25 26 27 28 29 30	31	32	33 34 35 36 37 38 39 40 41	42	43 44 45 46 47 48 49 50 51	52	53 54 55 56 57 58 59 60 61	62	72	77 78 79 80
														7	
														7	
														7	
														7	
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														7	
														7	
														7	
														7	
														7	
														7	

DIRECTIONS FOR KEYPUNCH: DO NOT PUNCH BLANK COLUMNS

NO UNDERPUNCHES IN SIGN FIELDS.

SKIN FRICTION DATA

MARK III

ENGINEER: ____________________

DATE: ______________

DIRECTIONS FOR KEYPUNCH	CASE		TYPE	
PUNCH IN ALL CARDS →			1,1	A E R Ø
DO NOT PUNCH BLANK COLUMNS	66	68	71	73 76

SURFACE NUMBER	Type — Flat Plate (0) — Tan-Cone (1)	Flow Type	Sum Turb (0) — Lam (1)		Skin Friction Method	Print Ave. C_f Data (1)	Print Flow Characteristics (1)	Print all Iterations (1) — Final (2)	WETTED AREA	LENGTH ~ FT	INITIAL LENGTH ~ FT	INITIAL TAPER RATIO	TAPER RATIO	T_{Wall} ~ °R Lam	T_{Wall} ~ °R Turb	η_{C_T}		SEQ. NO.
2			5			8			11	20	29	35	41	47	53	59	62	77 80
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
2			5			8			11	20	29	35	41	47	53	59	62	77 80

FLIGHT ATTITUDE DATA

MARK III

ENGINEER: ____________________

DATE: ________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE (66–68) TYPE 1, 2 (71–73) AERO (73–76)
DO NOT PUNCH BLANK COLUMNS

	α	β	K	QRP	η_c	θ/θ_{BODY}	q/q_α	IMPACT	SHADOW	DERIVATIVE FLAG	PRINT	PRINT SHOCK-EXP. CALCS.	NW	IMPACT	SHADOW	δ_e	R_{e_T}	T_{Wall}		SEQ. NO.
	1	7	13	19	26	31	36	41	43	45	46	47		49	51	53	58	62		77 80
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18																				
19																				
20																				
	1	7	13	19	26	31	36	41	43					49	51	53	58			77 80

PAGE______ OF____

COEFFICIENT INCREMENT DATA

MARK III

SHEET 8

ENGINEER:________________

DATE:____________

DIRECTIONS FOR KEYPUNCH	CASE (66–68)		TYPE (71–76)
PUNCH IN ALL CARDS → DO NOT PUNCH BLANK COLUMNS			1,3 A,E,R,0

	1 C_A	11 C_N	21 C_Y	31 C_l	41 C_m	51 C_n 60		SEQ. NO. 77 80
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

PLUNGE DERIVATIVE DATA

MARK III

PAGE____ OF____
SHEET 9

ENGINEER:________________

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DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS
DO NOT PUNCH
BLANK COLUMNS

CASE (66–68) | AERΦ (73–76)

CONTROL CARD

1 PART (= 1 WING = 2 BODY = 3 TAIL)

Group	Columns 1–10	11–20	21–30	31–40	41–50	51–60	61	TYPE (71)	SEQ. NO. (77–80)
Control card	PART (1)							14	
WING	AR	LAMBDA	M	SWBYS	CWBYC	S	K	15	
WING	CR	R	BETA	CLALW	CMWPR	KBW		16	
TAIL	AR	LAMBDA	M	SWBYS	GAMMAT	S	K	17	
TAIL	CR	R	BETA	CLALW	UPWASH	XBTBYC		18	
TAIL	KBW	Q						19	
BODY	VOLUME	S FRONT	LENGTH	X_O	X_C	C		20	
BODY	VOLUME	S FRONT	B					21	

PAGE ______ OF ______

SHEET 10

THRUST VECTOR DATA

MARK III

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DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS
DO NOT PUNCH
BLANK COLUMNS

CASE (66–68)		TYPE (71)	(73–76)
		2 2	A E R Ø

1 F ~ lbs.	11 X CENT	17 Y CENT	23 Z CENT	29 N_X	35 N_Y	41 N_Z	47	LAST 60	PRINT 62		SEQ. NO. 77–80
1	11	17	23	29	35	41	47	60	62		77 80

PICTURE DRAWING PROGRAM DATA

MARK III

PAGE ______ OF ______

SHEET 11

ENGINEER: ____________________

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DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → P,I,C (73–76)
DO NOT PUNCH BLANK COLUMNS

ELEMENT DATA TITLE — columns 1–59; CASE 66–68; TYPE 3,1 (71); SEQ. NO. 77–80

ELEMENT DATA CONTROL CARD — PRINT ELEMENT DATA (1); SYMMETRY FACTOR (3); USE SCALE FACTORS (5); X SCALE (7); Y SCALE (13); Z SCALE (19); ΔX SCALE (26); ΔY SCALE (32); ΔZ SCALE (38); NUMBER OF STATUS = 3 (60); ITAPE; IREWB (62); CASE 66–68; TYPE 3,2 (71); SEQ. NO. 77–80

VIEWING ANGLES — YAW, ψ (1); PITCH, θ (8); ROLL, ϕ (15); ICS (22); IREFL (24); ISHAD (26); IAREA (28); IQUAD (30); IFRAME (32); NCAM (35); MARKPT (38); N (43); M (46); I (50); J (53); NX (56); NY (58); LAST (60); CASE 66–68; TYPE 3,4 (71); SEQ. NO. 77–80

SCALES — Y_O LEFT (1); Y_O RIGHT (11); Z_O BOTTOM (21); Z_O TOP (31); ΔY_O (41); ΔZ_O (51); NO SCALE (60); CASE 66–68; TYPE 3,5 (71); SEQ. NO. 77–80

VERTICAL SCALE LABEL (1) — **HORIZONTAL SCALE LABEL** (31); 60; CASE 66–68; TYPE 3,6 (71); SEQ. NO. 77–80

PLOT TITLES — columns 1, 11, 21, 31, 41, 51, 60; 66, 68; SEQ. NO. 77–80

	TYPE
1	3,7
2	3,7
3	3,7
4	3,7

PHASE TERMINATION CARD (LAST CARD IN PHASE) — TYPE 9,9 (71); SEQ. NO. 77–80

PLOTTER PROGRAM CONTROL DATA

MARK III

PAGE ______ OF ____

SHEET 12

ENGINEER: ________________ DATE: ________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → P L Ø T (73–76)
DO NOT PUNCH BLANK COLUMNS

DATA SOURCE CONTROL

DATA SOURCE (= 0 READ FROM TAPE 9) (> 0 REAL FROM TAPE 5)

Columns 1–4; TYPE (71) 4,1; SEQ. NO. 77–80

VERTICAL TITLE

Columns 1–70 (10, 20, 30, 40, 50, 60); TYPE (71) 4,4; SEQ. NO. 77–80

HORIZONTAL TITLE

Columns 1–70 (10, 20, 30, 40, 50, 60); TYPE (71) 4,5; SEQ. NO. 77–80

PLOTTING GRID DATA

X_{LEFT}	X_{RIGHT}	Y_{BOTTOM}	Y_{TOP}	ΔX	ΔY	TYPE	SEQ. NO.
1	11	21	31	41	51–60	4,6 (71)	77–80

I(1) I(2) I(3) I(4) I(5) I(6) I(7) I(8) I(9) I(10) I(11) I(12) I(13) I(14) I(15) I(16) I(17) I(18) I(19) I(20) I(21)

Columns 1, 3, 6, 8, 11, 15, 18, 22, 27, 30, 34, 38, 41, 43, 46, 48, 50, 53, 56, 58, 61; TYPE (71) 4,7; SEQ. NO. 77–80

HORIZONTAL LABEL CARDS

Columns 1–70 (10, 20, 30, 40, 50, 60); TYPE (71) 4,8 / 4,8 / 4,8 / 4,8; SEQ. NO. 77–80

PHASE TERMINATION CARD (LAST CARD IN EACH PHASE)

TYPE (71) 9,9; SEQ. NO. 77–80

SLAB DELTA GEOMETRY DATA

MARK III

ENGINEER: ____________________ DATE: __________

DIRECTIONS FOR KEYPUNCH
PUNCH IN ALL CARDS → CASE (66–68) | SLBD (73–76)
DO NOT PUNCH BLANK COLUMNS

TITLE CARD

1–60	LAST (60)	TYPE (71)	SEQ. NO. (77–80)
		5 0	

SWEEP CARD

SWEEP (1)	NOSE RADIUS (11)	NUMBER OF $\Delta\theta$ BOT. (21)	TOP (23)	NO. SPAN (26)	ITθC (29)	MODE (31)	IREWB (36)	IBBSP (42)	IPRINT (48)	TYPE (71)	SEQ. NO. (77–80)
										5 1	

STATION DATA CARD

X-STATION (1)	ΔZ (11)	TOP T/C FACTOR (21)	BOTTOM T/C FACTOR (31)	ITOP (42)	LAST3 (60)	TYPE (71)	SEQ. NO. (77–80)
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	
						5 4	

PHASE TERMINATION CARD (LAST CARD IN EACH PHASE)

TYPE (71)	SEQ. NO. (77–80)
9 9	

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VOLUME I – USER'S MANUAL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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13. ABSTRACT

This report describes a digital computer program system that is capable of calculating the hypersonic aerodynamic characteristics of complex three-dimensional shapes. The outstanding features of this program are its flexibility in covering a very wide variety of problems and the multitude of program options available. The program is a combination of techniques and capabilities necessary in performing a complete aerodynamic analysis of hypersonic shapes. These include vehicle geometry generation and description, visual graphics necessary in handling geometry data and in preparing plots of the final aerodynamic data, aerodynamic calculations of surface pressures and skin friction forces, and the integration of these forces to give all aerodynamic coefficients and stability derivatives.

The geometric description techniques in this program provide the capability of handling completely arbitrary three-dimensional shapes. The procedure developed to check the accuracy of the geometric data uses a computer and automatic recorder to draw pictures of the vehicle viewed from any angle.

The pressure calculation methods provided within the program include modified Newtonian, blunt-body Newtonian-Prandtl-Meyer, tangent-wedge, tangent-cone, shock-expansion, Prandtl-Meyer expansion, blast wave, modified tangent-cone, boundary-layer induced pressures, free-molecular flow, and a number of empirical relationships. The pressure calculation method most suitable for each component of the vehicle is specified by the aerodynamicist. Viscous forces are also calculated and include viscous-inviscid interaction effects. Skin friction options include the Reference Temperature and the Reference Enthalpy methods (for both laminar and turbulent flow), the Spalding-Chi method (turbulent), and a special blunt body skin friction method. Control surface deflection pressures, including separation effects that may be caused by the deflected surface, are also calculated.

The program has been used to study a wide variety of hypersonic vehicle shapes including hypersonic cruise aircraft, air-breathing booster aircraft, blunt lifting reentry bodies, high L/D reentry vehicles, blunt reentry capsules, rocket boosters, reentry warheads, and satellite shapes.

The program is documented in two volumes. Volume I is primarily a User's Manual, and Volume II contains the Program Formulation and Listings.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Aerodynamics						
Arbitrary						
Three-Dimensional						
Shapes						
Hypersonic						
Flow						
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